School of Archaeology

GEM TESTING
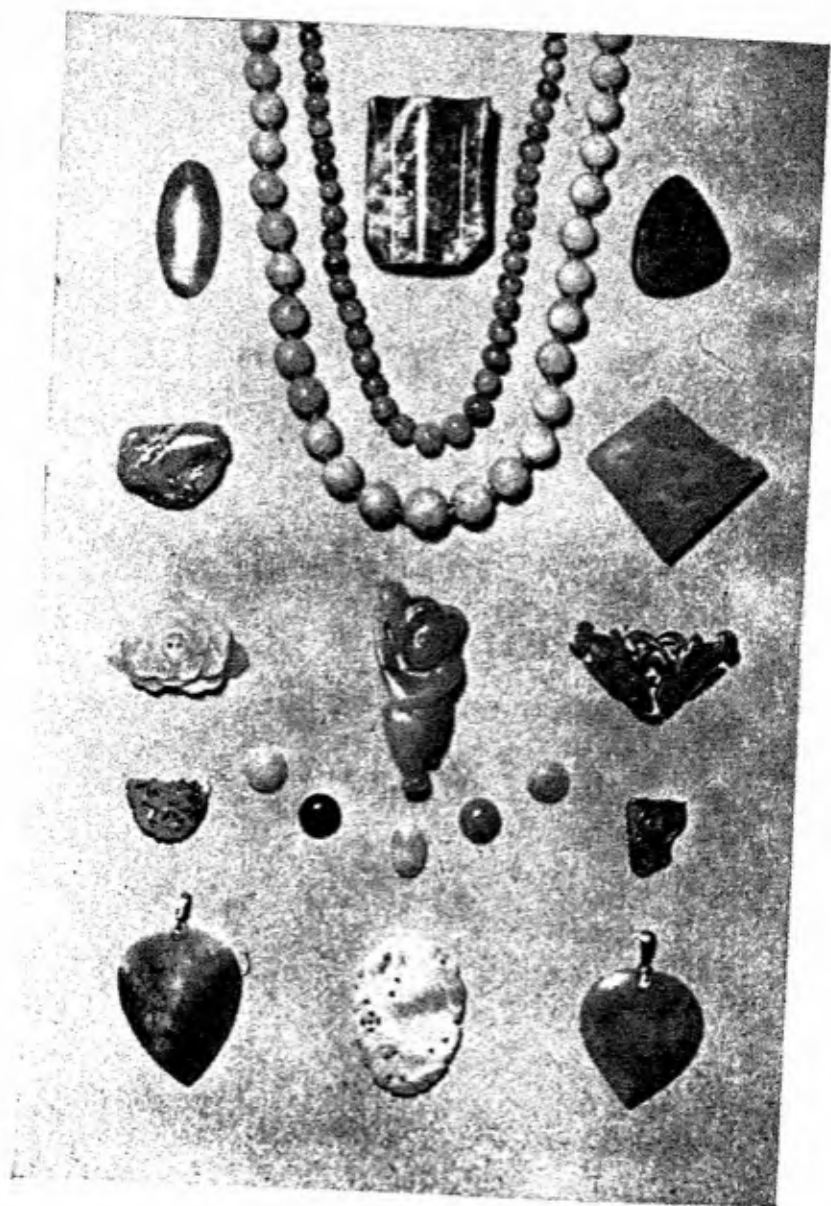
Jade-like Minerals

The bottom ten pieces, and the top necklet, consist of jadeite. The three centre carved specimens are nephrite. Centre top is a piece of Connemara marble: left top is grossular, and right top aventurine quartz. The lower necklace is amazon stone, flanked by chrysoprase (left) and bowenite (right).

GEM TESTING

by

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TO

C. J. PAYNE

WITH RECOLLECTIONS

OF HAPPY PARTNERSHIP

IN ROUTINE AND RESEARCH

EXTRACT FROM PREFACE TO
FIRST EDITION

THIS volume can lay claim to differ from any which have preceded it since, firstly, it is descriptive of gem-testing rather than of gems and, secondly, it has been written mainly with the ordinary jeweller and dealer in view. It aims at showing him in the simplest possible manner the easy scientific tests available to him for discriminating with certainty between one stone and another and between real stones and their substitutes, and how to apply these tests in practice.

The author has included only such tests and descriptions as seemed to him of really practical importance to the jeweller, and everything stated in the book is based on his own experience and knowledge. Although, as indicated above, the book is intended primarily as an aid to those who trade in precious stones, it is hoped that those of the general public who are interested in the subject may find it of some value, and more easily assimilated than most textbooks, and that students or even experienced gemmologists may find that the novel approach to the subject and the practical hints to be found in its pages make this something more than 'just another book on precious stones'.

EXTRACT FROM PREFACE TO
FIFTH EDITION

IN the period which has elapsed since the fourth edition of *Gem Testing* appeared there have been startling developments in the production of synthetic gemstones. Verneuil's 'flame-fusion' method, now half-a-century old, has been ingeniously modified to yield a spectacular new gemstone—synthetic rutile—and synthetic star rubies and sapphires. The appearance of the latter is somewhat disturbing, as it represents man's entry into a field in which Nature was thought to be inimitable. Full descriptions of the new materials and of other developments in synthetic, imitation, and 'faked' stones will be found in this edition, together with suggestions as to how they may be recognized.

There are other extensive additions and alterations to the book, the most important of which, perhaps, is the description of a new method of using the refractometer which was first suggested by Mr Lester Benson of the Gemological Institute of America. By using Lester Benson's 'Distant Vision' technique, the gemmologist can obtain refractometer readings on curved surfaces or on tiny faceted gems which give no visible shadow-edge under the normal method of observation. This represents a very valuable extension of the possibilities of the refractometer which every owner of this instrument should practise.

The chapter on the spectroscope has been re-written and improved, and the wavelength tables extended. Several further minerals have been included in the summary of gem species and in the tables at the end of the book, and a number of small alterations have been made to the text to make it more informative and more readable.

In making these additions and changes the author has tried to retain the simplicity of treatment implied in the original title of the book—*Gem Testing for Jewellers*—while increasing its usefulness to the more advanced gemmologist.

PREFACE TO SIXTH EDITION

THERE have been several important developments in the world of gemstones since the last edition of this book appeared in 1951. A new gem species—'sinhalite'—has been added to the list; and since this mineral had already been cut into gemstones fairly extensively (being accepted as stones belonging to other species) it obviously has an importance beyond the purely scientific interest that usually attaches to a 'new' gemstone.

Among the synthetic gemstones, the arrival of the long-heralded strontium titanate is also a matter of more than passing interest, since this stone is less easy to distinguish at sight from diamond than any other natural or artificial product. The synthetic emerald manufactured by Carroll Chatham in San Fransisco is intruding more and more upon the world's gem markets, and is causing some perturbation amongst those who deal in emeralds. And a new, sintered type of synthetic spinel has been marketed as a substitute for lapis lazuli, which, in appearance, it closely resembles. Red synthetic spinels have also appeared.

The latest first-hand information about these matters is given in this new edition.
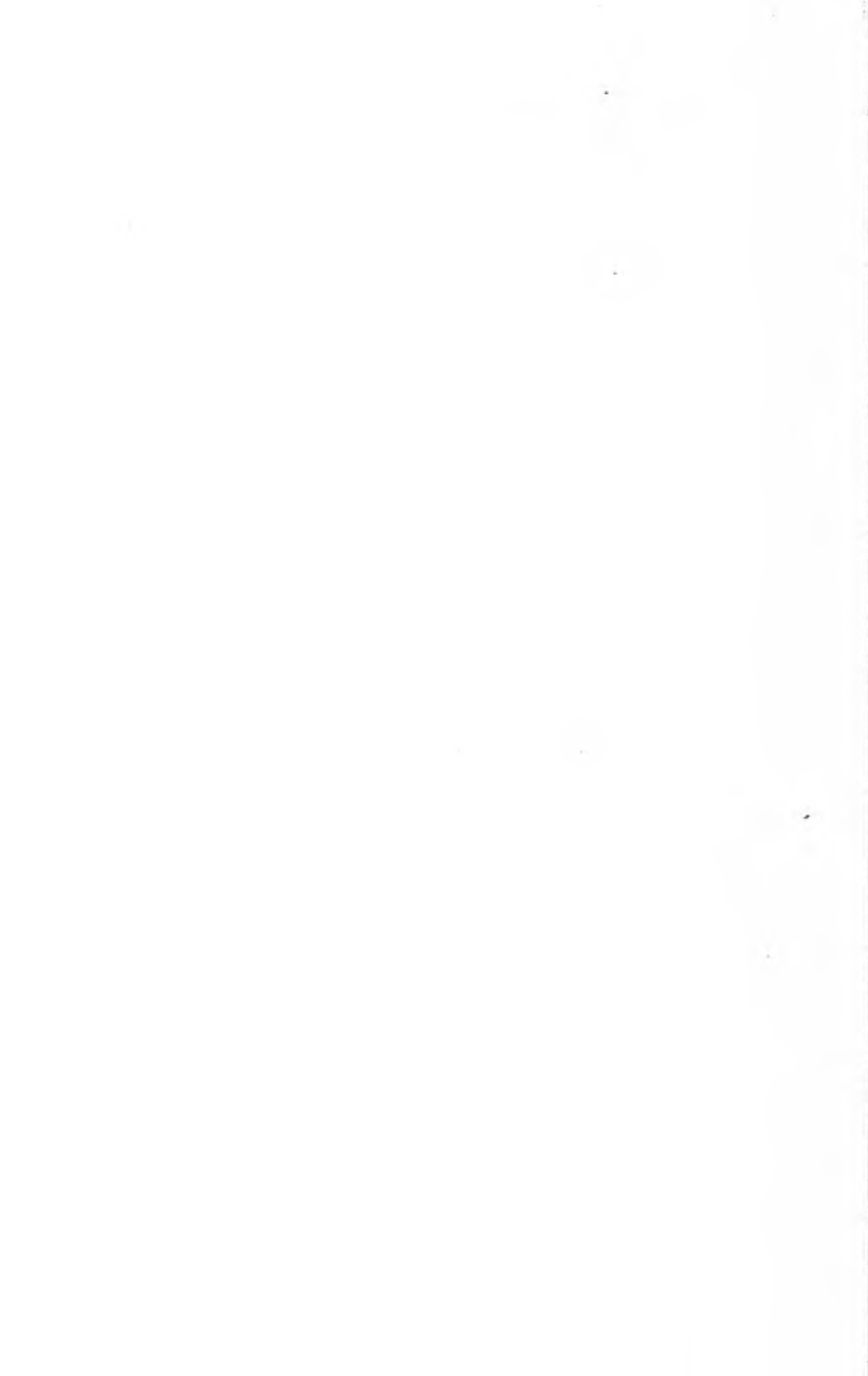
Developments have also taken place on the determinative side. Simple yet powerful methods such as 'immersion contact' photography and its offshoots, and the 'crossed filter' fluorescence technique, both of which were first introduced by the author, provide tools which can assist the gemmologist in some of his most difficult problems at little cost in the way of apparatus. These too are adequately described and illustrated in the text.

The chapter on the spectroscope has been newly illustrated from accurate drawings specially made by Mr T. H. Smith, and the text has been drastically re-arranged to make it more helpful for the jeweller or student who may have found this instrument difficult to handle with success. Also, a new chapter has been added on the subject of fluorescence, which, thanks to the researches of Mr Robert Webster and others, has lately been assuming a more important and definitive role than heretofore in practical gemmology.

Over and above these and other specific alterations or additions, the whole text has been carefully checked, revised, and altered where necessary to bring it more into line with modern ideas and practice, while at the same time retaining its essential simplicity. It is hoped that in its new form the book will not only be of greater usefulness, but will appeal to a wider circle of readers than ever before.

The author would like to thank his colleague Mr. C. J. Payne for help with the concluding refraction index table, and Mr. J. R. Chisholm for undertaking with characteristic good nature and thoroughness the arduous task of reading and correcting the proofs of the book.

B. W. A.

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CONTENTS

I

HOW TO USE THIS BOOK

AN explanation of the general plan of the book may be useful to the reader, as it does not follow orthodox lines. In the first place, it must be emphasized that the subject concerned is the *testing* of gemstones, and not their history, habitat, or general description. The early chapters give the reader information about simple apparatus and instruments, together with sufficiently detailed instruction in their use. Special attention is paid to those small points which often make all the difference between success and failure. Only just sufficient theoretical background is provided to allow intelligent use to be made of the tests.

A full description, plentifully illustrated from photomicrographs, of the characteristic features of synthetic stones, doublets, and pastes, is interposed before the chapter on the use of the microscope, with which it should be read in close conjunction, as the most important function of the microscope from the jeweller's point of view is to distinguish between natural stones and their synthetic counterparts. A simple account of the spectroscope as used in testing coloured stones concludes the first section of the book.

It may here be said that the reader will find the whole subject far more interesting and comprehensible if he puts together for himself a small collection of stones and tries out the various tests on his own specimens. Such a collection can be expanded or improved indefinitely, and can be a source of unending pleasure and interest to the owner and his friends or customers. Moreover, it is of great practical value to be able to turn at any time to a known specimen of a particular gem for direct comparison with a stone which is being tested.

Whilst show specimens may be attractively displayed in leather-lined cases with hollows or grooves to accommodate the stones, it is more practical to house the stones for a working collection in

'stone papers' and file them in alphabetical order in a cabinet or box. Data concerning the stones (locality, weight, physical properties, etc.) can be written on the outside of each packet, the whole thing forming an invaluable 'reference library'.

The remainder of the volume is concerned with directions for the practical application of the recommended methods in specific cases, beginning with the stones most important and familiar to the jeweller—diamond, ruby, sapphire, and emerald. In each case the distinctive properties of these well-known precious stones are described and compared with those of other stones and synthetic or imitation materials of similar appearance. Those tests which require little or no apparatus are always considered first, and each chapter contains a table showing the properties of the gemstones under review, and in many cases concludes with a summary suggesting a plan of campaign for establishing the identity of the stones in question.

The name of each stone as it comes under discussion in the text is printed in bold type to facilitate quick reference.

It must be admitted that the order in which the stones are treated amounts to a classification on a colour basis, which will be denounced by some purists as unscientific and undesirable on various grounds. Having carefully considered the 'pros' and 'cons' of this arrangement, the author decided that the resultant gain in helpfulness to those using the book more than outweighs the admitted disadvantages. Perhaps if readers are forewarned concerning the possible harmful effects of the arrangement, such effects may be somewhat mitigated. Firstly, then, a classification according to colour tends to obscure the virtual identity of stones which differ from each other only in colour and belong to the same mineral species. Thus, ruby and sapphire, here treated in separate chapters, are both colour-varieties of the same mineral, corundum, and are nearly identical as regards chemical composition, hardness, and density. Similarly, emerald and aquamarine are both beryls; amethyst, rock crystal, and citrine are all varieties of quartz, and so on. All this is clearly seen in the alphabetical list of gemstones at the end of the book. Secondly, the consideration, say, of all red stones liable to be mistaken for ruby, chiefly from the viewpoint of how they can be distinguished therefrom, is liable to foster a natural but deplorable tendency on the part of the jeweller to think of all such red stones as some sort of inferior or

imitation ruby, and thus blind him to the indisputable beauty and merit they often possess in their own right.

Fine red spinels, for instance, or fine red tourmalines, may compare unfavourably in colour with a fine specimen of ruby, but considered apart from this they are in themselves lovely and covetable stones, and they have nothing whatever in common with ruby except a certain superficial resemblance. It is only in the mind of man that such stones appear as competitors with the red corundum. Further, the less valuable gems are usually available in larger and more perfect specimens than can be obtained by even the millionaire in such gems as ruby or emerald, and can thus provide pieces suitable for pendants, necklaces or large brooches at a reasonable price.

Bearing the above points in mind, the jeweller is urged to realize that the arrangement adopted is followed simply for his own greater convenience—and it *is* an obvious convenience, since, for example, the possibilities to be considered when faced with a ruby-like stone are quite different from those arising when faced with a stone resembling that other corundum: sapphire. Further defence of the practical usefulness of colour in distinguishing gems will be found in its appropriate place in Chapter 4. The colour classification is not adhered to slavishly, as it was considered advisable to provide separate descriptions of zircon, the quartz group, the garnets, tourmaline, and peridot, in addition to mentioning their varieties under the appropriate colour heads.

The methods and apparatus dealt with in the first part of the book are chiefly concerned with the measurement of certain physical and optical properties which characterize the various gemstones. Practically all the gem materials are minerals, and the properties possessed by a given mineral species which distinguish it from other minerals depend upon two factors: (*a*) its chemical composition, i.e. the *kinds* of atoms with which it is built, and (*b*) its crystal structure, i.e. the spatial *arrangement* of these atoms within the mineral. Of these two factors, the latter is by far the more important, as can be sufficiently instanced by the two crystallized forms of carbon: graphite and diamond. These two minerals, so utterly contrasted in appearance and physical properties, are yet constructed of precisely the same kind of atoms; all the great differences between the two materials in hardness, transparency, density, and so on, must be laid to the account of the different

internal structure of their crystals. This fundamental importance of crystal structure, and the assistance given in recognizing gem minerals in the rough by a knowledge of the characteristic shapes of their crystals ('crystal habit') is recognized by all gemmologists, and in every textbook one of the opening chapters is devoted to elementary crystallography.

Now, experience with students of all ages has led the author to realize what a difficult barrier even this simplified form of crystallography is for the beginner to surmount, and in this book it was thought better to dispense with it entirely except for a table of crystal systems which will be found available for reference in the appendix at the end of the book. To enable the reader to make sense of certain references in the text, however, it may be said here that all crystals can be divided, according to their symmetry, into six main groups called the 'crystal systems'. These are named the cubic, tetragonal, hexagonal, orthorhombic, monoclinic, and triclinic systems. To the cubic system belong the most symmetrical crystals, and these are the only crystals within which light travels with the same velocity and character in all directions. In crystals belonging to any of the other systems the effect known as double refraction (see Chapter 3) takes place, in which a ray of light entering the stone is split into two polarized rays which travel with slightly different velocities through the crystal, and are therefore bent or refracted from their original course by different amounts. This is of high practical importance in testing stones, so that it is useful to bear in mind which are the gemstones that belong to the cubic system, and thus do *not* show this effect. These are diamond, the garnets, spinel, fluorspar, and others of lesser importance.

Tables and other useful features will also be found in the appendix, including a short descriptive list of books on precious stones for those who wish to extend their knowledge further, or form a small reference library on the subject, and names and addresses of firms who can supply the various instruments, etc., mentioned in the text.

The number of different minerals which have occasionally been cut as gemstones is very large, and it would spoil the simplicity and usefulness of this book for the majority of its readers to include all such possibilities in the text. For the benefit of fellow gemmologists who are interested in these out-of-the-ordinary

stones, the author has included most of them in the tables at the end of the book. With the aid of the data provided and the necessary simple instruments, it should be possible to identify these rarities when they are encountered. One of the rewards which occasionally awaits the keen gemmologist is the discovery of unusual stones in unlikely places: a kornerupine from an antique dealer's junk-box; a fine sphene in the centre of a paste brooch; a parcel of enstatites labelled 'dark olivines'; a museum specimen of spessartite rescued from a hessonite packet, even the discovery of a hitherto unknown mineral, are but a few of the instances of this kind known to the author.

Lastly, it is hoped that the somewhat scattered information in the book will be rendered quickly available to the reader by the provision of a full index.

REFRACTIVE INDEX AND ITS MEASUREMENT

OUR first task in identifying a gemstone is to make quite sure to what mineral species it belongs. For instance, is it a corundum (ruby or sapphire), a beryl (emerald or aquamarine), quartz (amethyst or citrine), topaz, tourmaline, spinel, peridot or zircon?

Though we can often make a shrewd guess as to the nature of a stone by reason of its colour, lustre, and general appearance, it is only by measuring one or other of its optical or physical 'constants' that we can be really sure of our ground. In this chapter methods are described for measuring the most important of these constants.

Man is a profoundly lazy creature and it has been said that most of his inventions have been born of the urge to save himself trouble. Presumably, therefore, jewellers who are not scientifically minded would welcome an apparatus which would enable stones to be identified in some really simple manner, quickly, clearly, and without calculation. If by merely placing the stone on an instrument its correct name could be read off on looking through an eyepiece, one would expect such an instrument to be popular and widely used.

Now, though no apparatus which 'names' the stones in this way yet exists (though one could probably be devised were it worth the cost and trouble), something nearly as easy to use is available in the jeweller's *refractometer*, several types of which are now on the market. In these, when the flat facet of a stone is placed on the glass table of the instrument (a drop of special liquid serving to make optical contact between the two surfaces) one can read through an eyepiece, if not the *name* of the stone tested, at least a number or pair of numbers corresponding to that particular stone. This number is given from the position of a shadow-edge which crosses a calibrated scale, and is known as the *refractive index* of the stone.

Each species of gemstone has its own characteristic refractive index or refractive indices by which it can be identified with more certainty than by any other simple means. The refractive index

of a mineral is now universally recognized as a property of the highest diagnostic importance, and it is a property which can be measured with speed and accuracy by any intelligent man or woman on an apparatus costing only about £16.

Before describing in detail the use of the refractometer we must give a brief explanation of what is meant by the terms 'refraction' and 'refractive index', and the general principles on which refractometers operate.

What happens when light falls on the surface of a transparent solid such as a gemstone? Some of the light is *reflected* at the surface of the stone, the reflected light leaving the surface at an angle equal to that at which it falls upon the surface ('incident angle' or 'angle of incidence'). It is this reflected light which provides the surface lustre of the stone. The greater proportion of the light, however, passes into the stone, but in this denser medium* it travels much more slowly than in air.
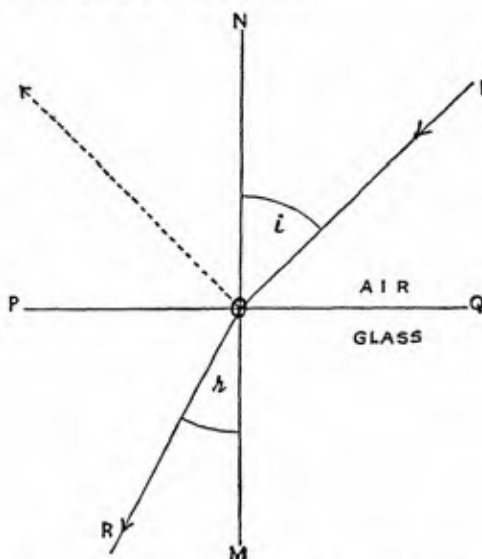
Figure 1. The ray of light IO is refracted on passing from air into glass along OR. NOM is the 'normal' (perpendicular) to the surface. The angle i is called the angle of incidence, the angle r is called the angle of refraction. The extent of refraction shown is given by ordinary window glass (R.I = 1·52)

* The term 'medium' is used to describe any substance through which light is travelling, and media are said to be dense or rare according to whether light travels relatively slowly or fast therein.

The effect of entering the denser medium, in which their velocity is diminished, upon trains of light waves striking the surface obliquely is to alter their direction and make them follow a new path nearer to the perpendicular (or 'normal' as it is called) to the interface between the two media.

This deviation of rays of light on entering a new medium is called *refraction*. In Figure 1 the ray of light, IO, is refracted along OR on entering the denser medium below the surface PQ. The broken line shows the path followed by the *reflected* light.

The extent of the bending or refraction of light on entering the stone depends upon its refracting power or 'refractive index', and this is inversely proportional to the velocity of light within the substance. Put differently, the refractive index of a medium may be defined as the velocity of light in air* divided by the velocity of light in the medium.

The velocity of light in air is approximately 186,000 miles per second, and light from the sun and stars travels to us at this immense speed. In quartz (rock crystal, amethyst, etc.) the velocity is reduced to approximately 120,000 and in diamond to only 76,860 miles per second.

Thus diamond, in which light travels, as mentioned above, at 76,860 miles per second compared with the 186,000 miles per second in empty space, has a refractive index of 186,000/76,860 = 2·42; higher than the refractive index of any other gemstone— accounting for the brilliant, adamantine lustre of the stone.

It has already been stated that each mineral has a definite refractive index by which it can be identified on the refractometer; lists of these indices will be found on p. 28, and at the end of the book.

For the benefit of those who like to have at least a rough idea of the working of an instrument which they are using, a short description of the basic principle upon which all gem-testing refractometers depend follows. However, those who would like to know how to use a refractometer, but who prefer to shirk such explanations, can skip the next section and await the strictly practical directions which will be given later, on page 22.

What follows can best be understood by considering the diagram, Figure 2. Here rays of light are considered passing from a dense medium into a rarer one, say from glass into air. The rays

* Or more strictly—a vacuum.

will then be refracted *away* from the normal, NOM (the reverse process of the former case considered in Figure 1).

Thus the ray AO is refracted along OA', apart from the small fraction of light which is reflected at O, as indicated by the dotted line.

Similarly, the ray BO is refracted along OB'. As we consider rays which form greater and greater angles with the normal,
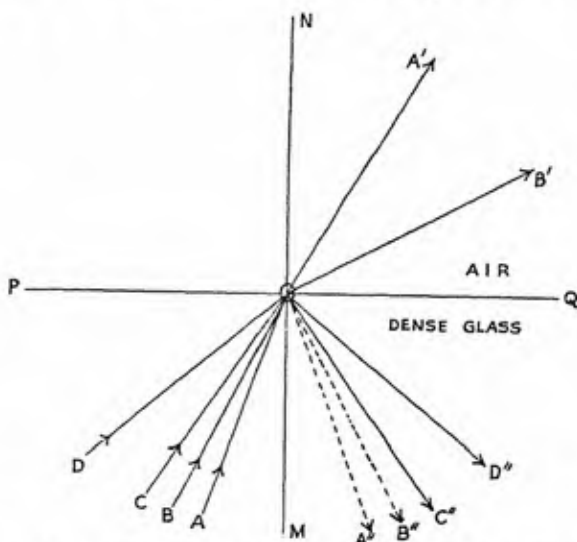
Figure 2. *Passage of light from dense glass* (R.I. *1·80*) *below into air above. The rays* AO *and* BO *are refracted along* OA' *and* OB' *and also partially reflected. Beyond the critical angle* COM = 34° *rays are totally reflected, being unable to pass into the rarer medium*

NOM, we reach an angle where the refracted ray only just grazes along the surface, OQ, between the two media.

This angle is known as the *critical angle*, and all rays reaching O from the denser medium at an angle greater than the critical angle are totally reflected back into the denser medium, it being physically impossible for any light from such rays to penetrate into the rarer medium.

In the diagram, the angle COM can be considered as the critical angle of incidence; all the light is thus totally reflected back along OC", and any other ray, such as DO, with a still larger angle of incidence, is, of course, also totally reflected. It is important to

realize that the *size of the critical angle will depend upon the relation between the refractive indices of the denser and the rarer medium*. If, therefore, in any two media which are in optical contact we can measure the angle where total reflection begins (i.e. the critical angle), and we know the refractive index of the denser medium, it is possible to calculate the refractive index of the rarer medium*.

This is the underlying principle of all total reflection refractometers (sometimes called 'total reflectometers'), but in the instruments designed for gem testing all calculation is ingeniously avoided. In such refractometers the optically dense medium of known refractive index is in the form of a polished hemisphere of heavy lead glass, or a segment of such a hemisphere, or a truncated 60° prism of the same material, the flat upper surface in each case forming the 'table' of the instrument. If the flat, polished surface of any gemstone which has a lower R.I. than that of the hemisphere is placed in optical contact with this table, rays passing through the glass to the stone will be mostly refracted into the stone, and thence escape into the air, when they strike the surface at less than the critical angle, but *totally reflected* back from the surface of the stone when they strike at an angle exceeding the critical angle.

There is a point here which may usefully be cleared up since it causes confusion to students. What is known as *the* critical angle of a stone is the angle at which rays of light passing *from the stone into air* are refracted at 90° to a line perpendicular to the surface. In other words, the refracted ray just grazes the surface between the two media. Rays striking the inside surface of a stone at angles greater than this critical angle cannot emerge, and are totally reflected back into the stone. Here, the stone is the denser medium, and the *higher the refractive index of the stone the smaller is its critical angle*.

In the case of a refractometer the principle is exactly the same, but here the glass of the refractometer is the denser medium, and the stone is the rarer medium. Thus, in this case *the higher the R.I. of the stone the greater is the critical angle between it and the glass of the instrument*.

The totally and the only partially reflected rays are projected by a lens system on to a transparent scale which is viewed through an eyepiece. The part of the scale illuminated by the totally re-

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* The formula is $n = n' \sin Ic$ where n is the unknown refractive index, n' that of the denser medium and Ic the critical angle.

flected rays will be brightly lit, while the rest of the scale will be relatively in shadow. The scale is calibrated by the makers of the instrument so as to read direct in refractive indices, so that by simply observing the position of the edge of the shadow on the scale the refractive index of the stone tested can be ascertained.

Refractometers of the total reflection type were in use during the latter half of last century, but the first satisfactory low-priced instrument for testing precious stones was devised by Dr G. F. Herbert Smith in 1907. This little instrument, made by J. H. Steward Ltd, London, is still on the market. The more recently

Figure 3. The 'Rayner' refractometer (improved pattern)

designed and very compact 'Rayner' refractometer has a truncated prism of dense glass in place of the usual hemisphere, but the principle of the instrument is exactly the same. The prism form was originally evolved to allow isotropic minerals to be used in place of glass. Special 'Anderson-Payne' models incorporating synthetic spinel, blende, and diamond have been made which have certain advantages as well as certain limitations compared with standard refractometers. In the Herbert Smith instrument the scale extends from 1·30 to 1·80. In 'Rayner' refractometers a denser glass is used and the scale extends from 1·30 to 1·86. In the spinel model the shorter range of 1·30 to 1·70 allows a more open

scale to be used, while the long upward range of the diamond refractometer, 1·55 to 2·05, necessitates a sliding eyepiece for scanning the scale.

Recently, several refractometers of American manufacture have become available in the U.S.A. These operate on precisely the same principle as the British types described in these pages, and the instructions given will apply to them equally well.

HOW TO USE THE REFRACTOMETER

Though the instruments are essentially very simple to use, the inexperienced person will fail to get the best results if he does not pay attention to certain particulars outlined below.

Firstly, there is the important question of illumination. Daylight may, of course, be used, and if so desired the 'Smith' and 'Rayner' instruments can be held in the hand of the observer while standing facing, and near to, a convenient window.

If the observer is right-handed he will probably prefer to hold the instrument in his left hand, leaving the right hand free to maintain the stone to be tested in contact with the table of the instrument.

During part of the year daylight is an uncertain commodity, and those who wish to use a refractometer frequently will be well advised to have some bench or table on which the refractometer can be placed in close proximity to a reading lamp. In the case of the 'Smith' instrument it will be found best to arrange a book or block of wood about 2 in. thick on which a piece of white paper has been laid. The refractometer is then placed on this raised platform and the light from a reading lamp with a 40- or 60-watt pearl bulb so arranged that it falls on the surface of the paper in front of the refractometer window.

A similar arrangement is convenient for the 'Rayner' (Figure 3), except that the light can pass direct from the lamp to the 'window' of the refractometer. The lamp should have a 'pearl' or 'opal' bulb, and be placed a little lower than the refractometer window.

In every case, if the illumination is correct, the observer should see on looking through the eyepiece a brightly and evenly illuminated scale. If this is not sharply in focus, the eyepiece should be adjusted by rotation.

We have now reached a point where all is in readiness to take

a refractive index reading. A supply of highly refractive liquid in a dropping bottle is provided with each instrument. Place a *small* drop of this liquid on the glass table of the refractometer. Then thoroughly clean the stone to be tested, and place it carefully on the instrument so that its table facet rests on the table of the refractometer, the liquid being flattened out into a thin layer which serves to exclude the film of air which would otherwise prevent the stone from making 'optical contact' with the glass of the instrument. If the stone is of fair size—say 3 carats upwards—it can safely be handled with the fingers, special care being taken to avoid scratching the soft glass of the refractometer. With smaller stones it is wise to use 'corn-tongs' in order to be quite sure that the stone is lowered into position with its table facet parallel to the glass. Similarly, in removing the stone from the instrument, larger stones are most safely handled with the fingers, smaller ones with tongs. A good plan in the 'Smith' or 'Rayner' types, where the glass is a little higher than the metal platform in which it is set, is to slide the stone gently from the glass to the metal, whence it can safely be picked up without any risk of damage to the glass. The best reading should be obtained when the stone is placed at the exact centre of the glass, but in some instruments better results may be obtained when the stone is slightly off-centre.

Now let us suppose that the stone has been correctly placed on the instrument (with liquid to make optical contact) and that the stone in question is a spinel.

Looking through the eyepiece, the observer should see part of the scale brightly illuminated, the remainder relatively in shadow. It will be seen that the point where the shadow cuts across the scale will be near 1·72, which is the refractive index for spinel (see Figure 4). The *exact* position of the shadow edge on the scale is not easy to estimate when using white light, as the edge is not a sharp one, but consists of a narrow spectrum owing to the fact that the relation between the refractive indices of the stone and the glass of the hemisphere is not the same for all colours (wavelengths) of the spectrum, the glass having a higher 'dispersion' than any of the gemstones which can be tested on it.

The reading should be taken at that part of the shadow where the green passes into the yellow and at the point of the slightly curved edge where the refractive index recording is at its highest. It should be mentioned here that in addition to the shadow-edge

due to the stone, a fainter edge should also be visible due to the liquid employed. This should read a full 1·81 on the 'Rayner' model and rather less than 1·79 on the 'Smith' instrument, in accordance with the different liquids provided. It may be noticed that this liquid shadow-edge is much more sharply defined than that due to the stone, owing to the closer approximations of the
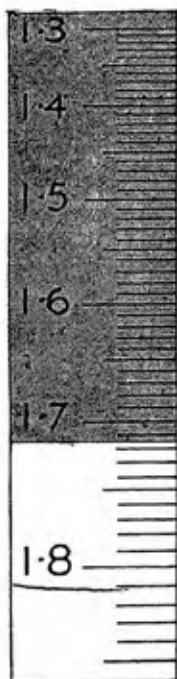
Figure 4. Shows, in a diagrammatic fashion, the observer's view of the scale of a 'Rayner' refractometer on which a spinel is in position, using sodium light. The reading is 1·715. The faint edge at 1·81 is due to the liquid

Figure 5. Shows, in a similar manner, the two edges which are seen with a peridot at their maximum possible separation 1·653–1·690

dispersions of the liquid and the glass of the hemisphere. With the 'Smith' and 'Rayner' refractometers the scale is an inverted one; that is, the lower parts of the scale represent the higher refractive indices. It may be mentioned that within its limited range the 'Anderson-Payne' spinel refractometer gives sharper and more accurate readings in white light than the other instruments. It

was indeed designed for this purpose. The synthetic spinel used for the prism has a very similar dispersion to those of the stones tested, so that the critical angle between prism and stone (upon which the position of the shadow-edge depends) does not vary appreciably whatever the wavelength of the light.

To obtain an absolutely sharp edge to the shadow with a standard refractometer one must use 'monochromatic' light, i.e. light of one colour or wavelength only; the standard and most easily produced light of this nature is the pure yellow light produced by glowing sodium vapour (wavelength 5893 Å). This yellow sodium light is easily produced if a Bunsen gas burner is available. Any substance containing sodium, such as soda (sodium carbonate), salt (sodium chloride) or window glass (a sodium calcium silicate), which is placed in the edge of the hot blue flame at its base will produce the desired yellow sodium flame. A sodium flame can be produced in a similar way with a spirit lamp by smearing salt on the wick, or adding some salt to the methylated spirit used as fuel. Such sodium flames are not very intense, but if used in a darkened room give quite clear results.

Once having seen the beautiful sharpness of the shadow produced with sodium light, the observer may well be reluctant to return to the use of white light again, though with the latter refractive index readings sufficient to identify a given gem are usually obtainable.

For those who can afford it, the most brilliant source of sodium light is obtained by use of a sodium discharge lamp. Where sodium light is not available shadow-edges can be improved by using a red glass or gelatine filter either between the light source and the instrument or over the eyepiece. The readings will be slightly higher than normal, but sharper than with any known *yellow* filter because more nearly monochromatic.

A dark yellow filter is issued by Rayner to fit over the eyepiece of their refractometer: if used in conjunction with a strong white light this is very effective.

As an actual example of refractive index measurement, we have so far mentioned only spinel, which gives a single shadow-edge near 1·72. If now the observer places a peridot on his refractometer he should see not one shadow-edge but two (in addition to the constant faint edge produced by the liquid).

The precise positions of the edges will vary according to the

orientation of the specimen, but it will be found that by carefully turning the stone on the table (keeping contact all the time) that a minimum reading is obtained with the lower edge and maximum with the other—*not necessarily in the same position*. With peridot these two important critical readings will be rather above 1·65 and about 1·69 respectively (see Figure 5).

This effect of two edges showing on the refractometer is due to *double refraction* and is shown by a large number of gemstones, though the separation between the two edges is greater in peridot than in any other of the common gemstones which give readings on the refractometer.

A single ray of light passing into any gemstone except those which crystallize in the cubic system is, in general, split into two rays which are refracted to a different extent.

For all such stones there is a maximum and a minimum refractive index and the difference between these two measures the extent of the double refraction.

Thus for peridot the double refraction is normally $(1·690 - 1·654) = 0·036$, for tourmaline $(1·638 - 1·620) = 0·018$, and for yellow topaz only $(1·637 - 1·629) = 0·008$.

In the last two examples we at once see the importance of the extent of double refraction from the testing point of view, since both topaz and tourmaline have a very similar mean refractive index; and, since a deep pink topaz is difficult to distinguish by eye from a tourmaline of similar colour, it is valuable to be able to distinguish between them on the refractometer.

This is easily done by observing the nature of the shadow-edges as the stone is rotated. With tourmaline the separation of the two edges can distinctly be seen even in white light, whereas with topaz the double refraction is too low to be distinguished clearly except on the spinel refractometer or in sodium light. A Nicol prism or its more convenient equivalent, a Polaroid disk, is of considerable assistance in detecting and measuring double refraction on the refractometer. Suitable polarizing caps to fit over the eyepiece are provided by the various makers. A polarizer only allows light to pass which is vibrating parallel to a certain direction. The rays corresponding to the two refractive indices in a doubly refractive stone are vibrating mutually at right-angles to one another, so that by turning the polarizer to the correct position one can see only the shadow-edge due to one ray, then,

by rotating the polarizer through 90° the shadow-edge due to the other ray is seen. Thus, even where the double refraction is insufficient to allow two edges to be seen in ordinary light, there will be noticed a slight shift of the edge when the polarizer is rotated, whereas with a singly refracting stone, such as garnet or spinel, no such variation should be observed.

The only important singly refractive stones which come within the range of the refractometer are fluorspar, opal, spinel and the garnets—hessonite, pyrope, almandine, and spessartite. The green demantoid garnet (misnamed 'olivine' in the trade), zinc blende (sphalerite) and diamond are also singly refracting but are beyond the range of the ordinary refractometer. Glass imitations also give a single edge on the refractometer, but this may vary in position from about 1·50 up to 1·70 according to the composition of the glass, and it is worth noting that *no singly refractive natural gemstone comes within the normal glass range*, 1·50 to 1·70, just mentioned.

When a singly refractive reading is seen in a region of the scale where no gemstone has its refractive index, one may at once suspect a 'paste'. The nature of the shadow-edge in white light is also revealing. Pastes with refractive index between 1·60 and 1·70 are lead glasses having a higher dispersion than gemstones of comparable index. This results in a *sharper* shadow-edge with the standard refractometer and a coloured edge when using a spinel refractometer. Doublets which have an almandine garnet front (as they often do) will give an almandine reading of about 1·79, which serves to identify the fraud.

A list of the refractive indices of the principal gemstones is given here for convenience. A fuller list will be found at the end of the book. The figures are given to two places of decimals only, but the double refraction is quoted to three places to enable small but often important distinctions to be made clearer.

Stones having refractive indices above the range of the refractometer are also included in the table. Although these give a 'negative' reading (i.e. a shadow-edge at the limit imposed by the contact liquid) this in itself gives valuable evidence as to the nature of the specimen. In common practice it limits the possibilities to certain almandines, to demantoid, zircon, diamond, and, less probably, sphene. These can easily be separated by their appearance, and by other characters described in later pages.

In certain species there is considerable variation in the value

Refractive Index Table

Gemstone	R.I.		D.R.
Fluorspar	1·43		—
Opal	1·45		—
Quartz...	1·54	1·55	0·009
Beryl	1·57	1·58	0·006
Topaz	1·62	1·63	0·008
Tourmaline	1·62	1·64	0·018
Andalusite	1·63	1·64	0·010
Spodumene	1·66	1·68	0·015
Peridot...	1·65	1·69	0·036
Spinel	1·72		—
Chrysoberyl	1·74	1·75	0·009
Hessonite	1·74		—
Pyrope	1·74		—
Corundum	1·76	1·77	0·008
Almandine-pyrope ...	1·77		—
Spessartite	1·80		—
Almandine	1·81		—
Demantoid	1·89		—
Sphene...	1·90	2·02	0·120
Zircon	1·93	1·99	0·059
Diamond	2·42		—

for the indices owing to variations in chemical composition. This is notably the case in the series of red garnets which vary more or less continuously from an 80 per cent pure pyrope, R.I. = 1·732, to an 85 per cent pure almandine, R.I. = 1·810. In the table typical representative figures are given.

By using sodium light, the skilled observer can obtain much more detailed information concerning the optical nature of the stones tested—whether they are 'uniaxial' or 'biaxial', 'positive' or 'negative', etc. Such factors are usually chiefly of academic interest, but can sometimes be of value in practical testing. A summary is therefore given of the effects seen.

(1) With singly refractive stones (amorphous or cubic), only one shadow-edge is seen, which remains immovable when the stone is rotated.

(2) With uniaxial stones (tetragonal and hexagonal), in general two shadow-edges are seen, one of which, corresponding to the extraordinary ray, moves, as the stone is rotated, towards and away from the immovable edge due to the ordinary ray. The index for the extraordinary ray is read at its greatest divergence from the ordinary; the difference between the two readings is then the birefringence of the stone. When the extraordinary index is higher than the ordinary the stone is optically positive; when less, optically negative.

Only if the table facet happens to be cut exactly at right-angles to the optic axis does the shadow-edge due to the extraordinary ray remain fixed (in its position of full birefringence) when the stone is rotated.

When the optic axis lies in the plane of the table facet a single edge will be seen when the stone is turned into a position where the axis lies parallel to the 'axis' of the instrument (i.e. the line between the eyepiece and the window through which light enters the instrument). The full birefringence will then be seen when the stone is turned until the optic axis is at 90° to the axis of the instrument.

(3) With biaxial stones (rhombic, monoclinic and triclinic), in general two shadow-edges will be seen, both of which may vary in position as the stone is turned on the refractometer. The maximum index obtainable with the higher R.I. edge should be read, and this corresponds with the value known as γ. The lowest index obtainable with the other edge should be noted separately, and corresponds to the value known as α. Then $\gamma - \alpha$ is the full birefringence.

A critical intermediate value, β, is not so easily obtained. It corresponds either with the lowest value for the higher edge or the highest value for the lower edge. The facet *may* happen to be cut in such an orientation that an optic axis (or even both axes) lies in the plane of the facet. In this case a single edge (corresponding to the β value) will be observed in certain positions.

The convention is that when β is nearer in value to α than to γ the stone is optically positive; when nearer to γ than to α it is negative. In practice it is seldom necessary to ascertain the exact

value for β. If the higher R.I. edge is seen to move beyond the half-way position between maximum and minimum readings it must be positive. If the lower R.I. edge moves past the half-way position, the stone is negative.

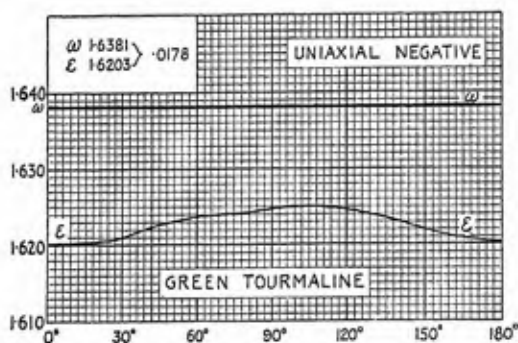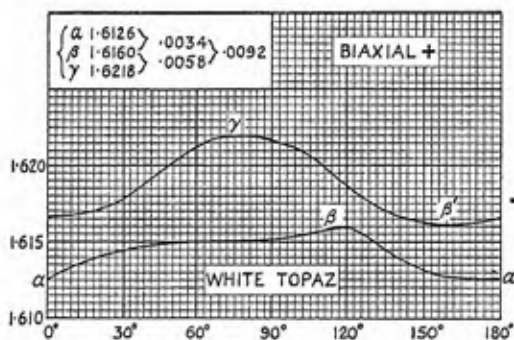*Figure 6. Movement of shadow-edges observed in a specimen of green tourmaline*

Figure 7. Movement of shadow-edges observed in a specimen of white topaz

Advanced gemmologists may find it interesting to deduce the crystal orientation of a cut stone by the careful observation of shadow-edge movements, but for the purposes of identification maximum and minimum readings are all that are normally

necessary. *It can be stressed that for all stones, uniaxial or biaxial, the difference between the maximum and minimum readings obtainable on any facet must always represent the full birefringence for that stone.* This is a fact of the highest diagnostic importance.

The diagrams reproduced in Figures 6 and 7 demonstrate typical shadow-edge movements in uniaxial and biaxial stones.

Useful and simple methods for detecting double refraction without the aid of a refractometer will be discussed in the next chapter.

'DISTANT VISION' METHOD FOR CABOCHON STONES

To obtain accurate readings on the refractometer it is essential that the stone should have a flat, polished facet to make good contact with the glass of the instrument. However, research workers of the Gemological Institute of America* developed and described an ingenious and important new technique whereby modified refractometer readings can be obtained even with cabochon stones or with faceted stones which are too tiny to give a shadow-edge in the normal way. Benson's method (known in America as the 'spot' method and in Britain as the 'distant vision' method, for reasons which will be obvious in what follows) is neither so easy to apply nor so critically accurate as the standard method, but it enlarges so enormously the scope of the refractometer that the keen gemmologist is strongly recommended to take the necessary trouble to become proficient in its use, as it will enable him to make identifications where the normal procedure fails.

Chrysoberyl and quartz cat's-eyes, for instance, sometimes so difficult to distinguish with certainty when mounted in jewellery, show their great difference in refractive index in clear-cut fashion, as do cabochons of nephrite or jadeite and the several massive green minerals with which they may be confused. Turquoise too, which in the normal way is reluctant to show a shadow-edge even from a flat surface, also yields quite a distinct effect by the new method, and quite tiny faceted stones are also made to give a reading.

The procedure, when using a standard Rayner refractometer,

* Lester Benson: 'Refractive indices of cabochon cut stones'; *Gems and Gemology*, Summer, 1948. Also J. R. Crowningshield, ibid. Summer, 1949.

is as follows. The first essential is to limit the amount of the contact fluid to the smallest possible droplet. This can be done by applying it with a fine glass capillary tube or a fine wire or needle, or by touching the stone on an ordinary small drop, withdrawing it, and wiping the main drop away, using only the minute quantity adhering to the stone. The stone (we will suppose it to be a cabochon) is now allowed to rest in the centre of the refractometer table: the point of contact will be slightly enlarged by the trace of contact liquid, and if the eye be withdrawn about twelve inches away from the eyepiece and the head moved slightly until the correct position is found, it should be possible for the observer to see the point of contact of the stone and liquid droplet as a little disk in the middle of the limited portion of the scale still visible at such a distance.

If the eye (and the attention) be focused on this contact spot the scale readings will be, unfortunately, slightly out of focus, but by a slight lateral movement of the head and an effort of will the position of the spot on the scale can be gauged fairly closely. It will be found that if the contact spot be viewed against index readings which are below the refractive index of the specimen, it will appear completely dark.

On gradual alteration of the vertical line of vision towards the higher index readings, beyond a certain point the contact spot will be seen to change from dark to light (as total reflection sets in). With care and practice the critical position can be found where the spot is bisected by the dark shadow. *A reading of the scale at this point will give the refractive index of the stone.*

Practice in the method should be gained with such things as beads or cabochons of quartz, moonstone, or other known minerals, or with faceted stones which, though small, are just large enough to show a shadow-edge when using the refractometer in the normal manner. Thus confidence in the new technique will be gained before an attempt is made to tackle an unknown specimen.

CARE OF THE REFRACTOMETER

When new, the glass surface of the refractometer hemisphere or prism is beautifully flat and perfect, and will give very dense shadow edges. It is well worth while to try and maintain this surface in good condition by protecting it from mechanical damage due to careless placing of the stone thereon in such a way

that an edge or corner of the stone scratches the soft glass, and from what may be called chemical damage from allowing the highly refracting liquid (which is usually methylene iodide with one or more solids dissolved in it) to remain on the glass after the test is made. Strips of clean blotting-paper should be kept at hand to wipe away the surplus liquid and the glass then rubbed with a clean wash-leather when the test has been completed. A smear of Vaseline on the glass when the instrument is not in use is an additional protective measure. If the glass should have become affected and is giving poor readings, a useful tip is to clean it with a little wad of cotton wool dipped in a paste of jeweller's rouge and water. This will produce sparkling results. If the surface has become seriously damaged, however, it will be best to return it to the makers, who will re-polish it for a cost of about £3.

Heavy pressure on a specimen while taking a reading should be quite unnecessary, and often gives rise to damage in the soft glass of the refractometer. Normally the weight of the stone itself is quite sufficient to make good optical contact with the table of the instrument.

It is worth noting that some pastes fail to give a shadow-edge on the refractometer, owing to their having a thin surface film of slightly different refractive index from that of the main body of the glass. Such a 'coating' is probably accidentally induced during manufacture. Deliberately 'coated' stones have been recently introduced (see end of Chapter 6) which also fail to give refractometer readings. In either case, a brisk rub with a rouged cloth will usually clean the surface of the specimen sufficiently to enable clear readings to be obtained.

'BRIGHT LINE' TECHNIQUE

In cases where readings are difficult to obtain under the ordinary lighting conditions, C. J. Payne has often found the following technique to give good results. The hood of a Rayner refractometer is pulled out of its socket, and the window through which the light normally enters the instrument is blocked. An ordinary safety-match box accomplishes this very neatly. A microscope lamp (or sodium lamp) is then so adjusted as to provide light at grazing incidence on the stone when it is placed on the refractometer table. If these conditions are correctly carried out it is

usually possible to see a *bright line* crossing the scale in the position where the shadow-edge would normally appear. It may be necessary to rotate the stone for the effect to be clearly seen. With birefringent stones, of course, two bright lines should be visible.

Although, as we have seen, by means of the 'distant vision' method it has now been found possible to use the refractometer with stones having curved or very small·flat surfaces, there are still cases where some different method of refractive index determination may be necessary. For instance, where uncut or carved stones are being tested, or numerous small stones set in a brooch or eternity ring; or where the setting makes contact with the refractometer glass impossible. The immersion methods described below are particularly suitable in such cases. All that is required in the way of apparatus is a glass dish or cell and small bottles containing various liquids, specified later. A microscope increases the scope and accuracy of the method greatly, but the required information can often be obtained without its aid.

The theoretical basis of the method is as follows. Transparent objects can only be 'seen' by the refraction and reflection of light at their surfaces, and where a transparent solid is immersed in a liquid of nearly the same refractive index refraction and reflection are reduced to a minimum and the solid becomes virtually invisible. Lumps of ice in a tumbler of water form a familiar example of this effect, and it is easy to prove by experiment that the degree of visibility, or 'relief' as it is called, of a transparent object immersed in a transparent fluid depends entirely upon how nearly the refractivity of solid and liquid approximate to one another.

Thus if we can find a liquid in which the outline of the stone, when immersed, becomes so indistinct that it almost vanishes, we can safely assume that the refractivity of the stone is very near to that of the (known) index of the liquid. Good examples of this are fire opals in carbon tetrachloride, moonstone or orthoclase in chlorobenzene and quartz in ethylene dibromide.

Of the many possible liquids, the following list provides a useful range, and includes so far as possible those which are readily available and least obnoxious.

Carbon tetrachloride	...	...	...	1·46
Toluene...	...	...	...	1·50
Monochlorobenzene	...	...	...	1·526
Ethylene dibromide	...	...	...	1·54
Monobromobenzene	...	...	...	1·56
o–Toluidine	...	...	...	1·57
Bromoform	...	...	...	1·59
Monoiodobenzene	...	...	...	1·62
Monobromonaphthalene		...	...	1·66
Monoiodonaphthalene		...	...	1·705
Methylene iodide	...	...	...	1·745

Mixtures containing methylene iodide, which are necessary for higher indices, are expensive and not very pleasant to handle. Phenyldi-iodoarsine (R.I., 1·85) though useful in the laboratory, is very poisonous, and has a violent blistering action on the skin: it is thus emphatically *not* recommended for any but the skilled worker who is prepared to take the necessary precautions.

Where stones are sizeable and have a polished facet available the refractometer of course provides the most convenient, rapid, and accurate test. But there are many cases where the refractometer cannot be applied, and immersion methods then come into their own, particularly when used in conjunction with the microscope. One may be faced with a brooch, for instance, set with tiny diamonds, some of which, it is suspected, have been replaced by synthetic white sapphires. If the whole brooch be immersed in methylene iodide and the stones viewed under a low-powered microscope the diamonds can at once be distinguished by their high relief (every facet showing clearly) in contrast to the white synthetics which have hardly distinguishable edges. Any intruders, indeed, into a group of small stones mounted or unmounted, purporting to be all of the same kind, can very easily be descried by immersion in an appropriate liquid.

When stones are free from their setting, it is quite easy to see whether they have an index higher or lower than that of a liquid in which they are immersed by placing a sheet of white paper under the glass dish in which the stones are resting (table facet down) and viewing them by light from a single overhead lamp. If a stone has an index *higher* than that of the fluid, it will cast a dark-rimmed shadow on the paper below, and the projection of

the facet edges will appear white. If the stone has a *lower* index than that of the fluid it will show a bright margin and the facet edges will appear as dark lines. The breadth of the border margin will give a good idea of the degree of the difference which exists between the indices of stone and fluid in each case. Where there is nearly a perfect match, a coloured margin will appear, showing that the fluid index coincides for some wavelengths with that of the stone, but (as it has higher dispersion than the stone) not for others.

The effects could more easily be seen if viewed from below; and it is quite easy to devise a means for doing this. Two wooden blocks, or hollow cubes made from cardboard, are placed so as to flank a third, wedge-shaped block of wood or card, the sloping
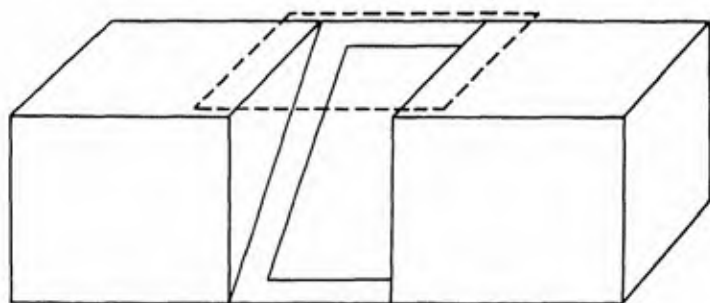

Figure 8. Diagrammatic sketch showing two cardboard cubes and wedge-shaped support for mirror, as recommended for study of immersion contrast effects

The dotted line indicates the position of the ground-glass 'bridge' on which the immersion cell containing the stones is to be placed. A single overhead light reveals striking differences in contrast when the observer views the immersed stones in the mirror

(45°) face of which confronts the observer. On this sloping surface is fixed a piece of mirror (of the type that ladies carry in their handbags). The two outer blocks are bridged by a sheet of finely ground glass (obtainable from any photographic dealer) and on this the glass dish containing the immersed stones is placed. When this is illuminated by an overhead light the observer sees a beautiful display of 'immersion contrast' in the mirror, which of course reflects the image of the undersides of the immersed stones as projected on the ground-glass screen. The diagram reproduced as Figure 8 gives a clear idea of this simple and effective arrangement.

Figure 9. *Immersion contact photograph of stones immersed in monobromonaphthalene*
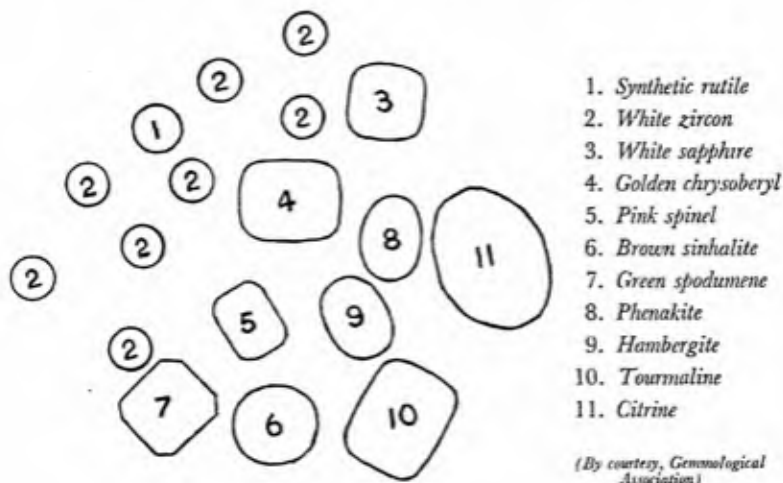
1. *Synthetic rutile*
2. *White zircon*
3. *White sapphire*
4. *Golden chrysoberyl*
5. *Pink spinel*
6. *Brown sinhalite*
7. *Green spodumene*
8. *Phenakite*
9. *Hambergite*
10. *Tourmaline*
11. *Citrine*

IMMERSION CONTACT PHOTOGRAPHS

Another development of the same general technique is to place the dish of immersed stones over a piece of bromide printing-paper or slow 'line' or 'process' film in a dark-room, and expose for a second or two to light from an overhead lamp. The developed negative gives a beautifully clear pattern of the stones showing their index in relation to that of the immersion fluid in no uncertain manner. The photograph in Figure 9 shows an example of such an immersion contact photograph, in which stones with

(By courtesy, Gemmological Association)

Figure 10. Immersion contact photograph of tourmaline necklace in bromobenzene (index 1·56) revealing presence of five aquamarine beads (in low contrast)

a wide range of refractive index are immersed in monobromo-naphthalene.

Figure 10 is another immersion contact photograph of a stone

necklace, reputedly of variously coloured tourmalines, immersed in bromobenzene. The presence of five aquamarine beads, nearly matching the fluid, is clearly revealed.

Such photographs will also serve to record the exact size and shape and facet distribution of a cut gemstone. For this purpose, however, a liquid should be chosen which has a refractive index near that of the stone. A further practical use of such photographs to the gemmologist has recently been discovered by the author. Synthetic stones are found often to reveal the curved 'structure lines' by which their synthetic origin can be assured in immersion contact photographs, even where these lines are not visible to the eye or under the microscope. This will be further discussed in the chapter on synthetic stones (Chapter 6).

When dealing with stones in the rough—amber or imitation amber beads, jade ear-rings, and the like (none of which can be tested on the refractometer)—it is often feasible to detach a tiny fragment without harming the specimen, and the chip can be placed on a plain glass slide, a drop of liquid placed on it, and examined under the microscope. In addition to noting the relief or lack of relief shown by the fragment in the particular liquid used, information can readily be obtained as to whether the chip or the fluid has the higher index, in the following manner. The sub-stage condenser (if used) is lowered and the microscope sharply focused on the edge of the chip. The focus is then raised and lowered alternately above and below the true position and the effect observed. If the lighting has been correctly arranged, a bright line, following the contour of the specimen, will be seen alternately to move into and spread outwards from the fragment.

The rule is simple to remember, that when the focus of the microscope is *raised* the bright line passes into whichever medium has the *higher* index. Conversely, when the focus is *lowered* from the position of sharp focus the bright edge passes into the medium of *lower* index. It is wise to practise the effect with fragments and liquids of known index before attempting to work on an unknown specimen.

Various fluids can be tried in succession, draining away one drop with a small piece of blotting-paper before applying the next. Observation of the bright line can be carried out also at the edges of quite large faceted specimens immersed in liquid, and it also provides a means of determining whether the microscopic

crystals to be found as inclusions in most gemstones have a higher or lower refractive index than the stone which encloses them. Here again the degree of relief gives information as to how different or how similar are the indices of the included and including minerals. Unfortunately, since the smaller crystal is permanently 'immersed' within a solid, only the one experiment can be carried out on these lines.

As with the heavy liquid method for determining density, which is described in Chapter 5, immersion methods can either be used as a rapid means of gaining an approximate value for the refractive index of a stone (which is often all that is necessary to discriminate between two possible alternatives) or it can be used with care and skill to obtain quite accurate measurements. Mineralogists have elaborated the technique to a high degree of perfection.

Quite apart from measurement of the refractive index of a stone, immersion of specimens in liquids will be found most valuable in revealing the distribution of colour, the presence of inclusions, the detection of doublets, and so on, as recommended in later chapters. In assessing the suitability of rough stones for cutting, the lapidary would find his task simplified if he immersed his specimens in a dish or cell of (say) benzene, or even of water. Flaws, colour distribution, and so on, can thus be much more clearly seen.

3

DOUBLE REFRACTION
AND HOW TO DETECT IT

WHEN discussing the use of the refractometer in the preceding chapter, reference was made to the curious phenomenon of *double refraction*, which is characteristic of all minerals which crystallize in systems other than the cubic system. This means that the splitting of a single ray into two polarized rays which have different velocities and therefore different refrangibility is observable in all the common gem minerals except the garnets, spinel, and diamond, which crystallize in the cubic system. The 'strength' of the effect in the various stones differs considerably, and this fact is important as an aid to identification.

Double refraction is measured numerically as the difference between the least and greatest refractive indices for the stone; some figures will be found in the table of refractive indices given on p. 28, but for convenience a selection of values are given here. In diminishing order of birefringence (birefringence is another term for double refraction) we have

Rutile	...	0·287	Spodumene	...	0·015
Calcite	...	0·172	Quartz	...	0·009
Sphene	...	0·12	Chrysoberyl	...	0·009
Zircon	...	0·059	Topaz	...	0·008
Peridot	...	0·036	Corundum	...	0·008
Tourmaline	...	0·018	Beryl ...	...	0·006

In some minerals the figures vary somewhat; thus in zircon, while the blue, white, and golden 'fired' types most popular in modern jewellery are almost constant in their birefringence of 0·059, many of the Ceylonese zircons, particularly the green varieties, have a much lower double refraction, sinking in some cases practically to zero. This peculiarity of zircon is unique amongst minerals, and will be discussed at greater length in the chapter on zircon. Rutile has recently been manufactured in the U.S.A. (see p. 86), and its enormous double refraction will be one means of identification. Calcite, though not a gemstone, plays an important part in gemmological instruments in its optically pure form of 'Iceland spar'.

How, apart from the refractometer, can one test whether a given stone is doubly refractive or not? The simplest method of all, which with a little practice is quite easily carried out, is to examine the stone carefully with a powerful pocket lens—say one giving ×8 to ×12 magnification. For example, look through the table facet of a zircon with a lens, and focus sharply on to the edges of the back facets where they adjoin the culet, and it will be noticed that instead of a *single* sharp line where the facets join, as would appear in a singly refractive stone such as diamond, each edge appears as a *double* line (see Figure 12).

A word of warning, however, should be uttered here; according to their crystal structure, all doubly refracting stones have either one or two directions in which only single refraction obtains. Those gemstones belonging either to the tetragonal or the hexagonal system of crystals have only one such direction; one 'optic axis' as it is called. These minerals, which are grouped together optically as 'uniaxial', include zircon, corundum (ruby and sapphire), beryl (emerald and aquamarine), tourmaline, and quartz (amethyst and citrine). The minerals crystallizing in either the orthorhombic, monoclinic or triclinic systems have two optic axes, and are called 'biaxial'. These include peridot, chrysoberyl (alexandrite), topaz, and spodumene (kunzite) among the commoner gemstones.

Thus it must be realized that if, say, a zircon is cut with its table facet at right-angles to its optic axis it may be necessary to tilt the stone and make observations through the bezel facets to see the double refraction well developed.

With zircon, sphene, and peridot the birefringence is so strong that even the novice should have no difficulty in seeing the effect mentioned even in small stones, but it needs a practised eye to detect the doubling effect in quartz and corundum unless the stones are large. As with any other test, practice begets competence, and when the beginner has become accustomed to getting results in easy specimens he should strive to develop his skill to the limit and learn to gauge approximately the strength of the double refraction shown. The author has found this to be a most valuable accomplishment. The more things that can be learned with a pocket lens the better—even if one possesses other apparatus this will not usually be available in an auction room or on other people's premises. This same test can, of course, be extended

and rendered easier by using a microscope, which functions as a much more powerful lens, magnifications of 25 to 60 diameters being quite comfortably usable with the stone held between the thumb and forefinger of the left hand, supported on the microscope stage.

A more sensitive test for double refraction than those mentioned above is possible by using polarized light. A ray of ordinary light, vibrating in all possible directions at right-angles to that of the ray, becomes transformed when passed through a Nicol prism or a sheet of Polaroid and emerges in a polarized condition. Polarized light is indistinguishable from ordinary light to the unaided eye, but the fact that it is vibrating in one plane only gives it peculiar properties which are of great value in the study of minerals. A detailed description of the uses of polarized light would be beyond the scope of this book, but since the arrival of the artificial compound Polaroid has made polarized light available to all at a low cost a brief account of its use in detecting double refraction will be attempted here. Those who would like further information on the subject are advised to consult any good textbook on mineralogy.

A ray of light entering a doubly refracting mineral is in general split at once into two polarized rays vibrating in planes at right-angles to each other. These are each slowed down to a different extent in passing through the crystal structure, and are thus refracted differently. What is important to realize in the present connection is that along any one direction in a doubly refracting stone only two sorts of ray can travel, and these are vibrating at right-angles to each other and in directions which are rigidly fixed by the orientation of the ray to the structure of the stone.

Now a beam of light which has passed through a Polaroid disk (or Nicol prism) and is vibrating, shall we say, north and south, will be quite unable to pass through another disk or prism which is set with the vibration direction at right-angles to this, i.e. east and west. Such a system through which virtually no light can pass is referred to as 'crossed Nicols' or 'crossed Polaroids'. If one of the Polaroids or Nicols is turned ever so slightly from the 90° position some light will be able to pass through, and more and more light will come through on further turning till the maximum is reached with the two disks in a 'parallel' position (see Figure 11).

Now if between two crossed Polaroids a piece of glass is inserted

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the darkness of the field will remain unaltered (unless the glass has been badly annealed) since glass, being amorphous, imposes no change in the vibration direction of light from the first Polaroid disk. But this is not the case when a doubly refractive gem is placed between the Polaroids.

Unless the vibrations of the rays passing through the crystal are parallel to those of the polarizers, a certain amount of light can now pass through the second Polaroid.

Thus the effect of rotating a doubly refractive gem between
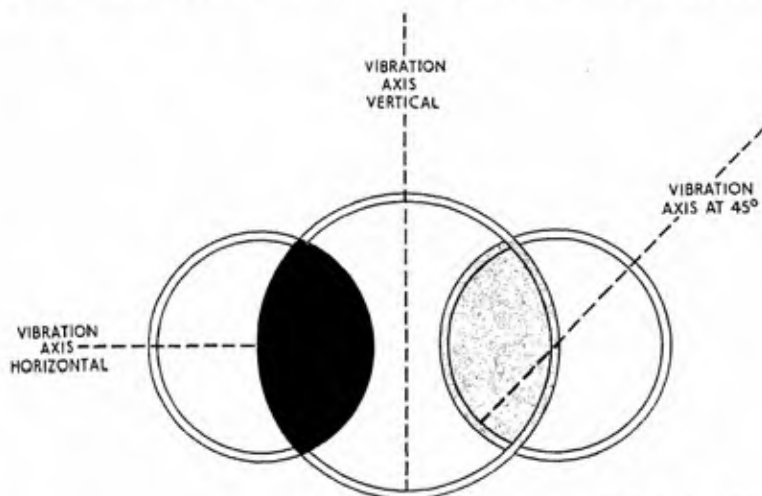
(*After H. S. B. Meakin Ltd.*)

Figure 11.   Three Polaroid screens showing the effect upon the transmitted light by crossing the vibration axes

crossed Polaroids is in general to give four positions of darkness 'extinction' (at intervals of 90°) in a complete revolution and four positions of maximum brightness.

This provides the most usual means by which the mineralogist distinguishes between singly refractive (amorphous or cubic) substances on the one hand and doubly refractive stones on the other. Glass or cubic minerals under strain show 'anomalous' double refraction between crossed Nicols, but the effect is not likely to be confused with true double refraction since the extinction is not clear-cut all over the field, but mottled or grid-like. Almandine garnet and diamond often show anomalous double refraction. Natural spinel is usually quite isotropic, but synthetic spinel always

displays anomalous effects resulting in a 'tabby' extinction which is a helpful feature in identification.

Undoubtedly the most comfortable and efficient way of studying these effects is by means of a polarizing microscope with rotating stage. Such instruments are expensive, and hardly worth while for the jeweller, but with the aid of pieces of Polaroid an ordinary microscope can be made to function quite well, one Polaroid disk being mounted below the stage and the other used as an eyepiece cap which can be turned into the extinction position before making the test. Even without a microscope the test can be made either by mounting Polaroids after the fashion of the old 'tourmaline tongs' or with a short length of tubing with Polaroid at either end and an aperture for inserting the stone between the Polaroids.

The Rutland polariscope, made by Messrs Rayner, is one of the least expensive and most convenient of the many models of hand polariscope using Polaroid which are commercially available. An inexpensive and convenient table polariscope with built-in lighting is made by H. S. B. Meakin Ltd, and can be recommended.

The presence or absence of double refraction often provides us with an easy and certain means of discriminating between the real and the false. Glass or 'paste' may have local strains within its structure which will cause it to show 'anomalous' double refraction to some extent when tested between crossed Nicol prisms; but in no glass or singly refractive gem will such strain effects be sufficient to cause any of the 'doubling' phenomena described above. To give a practical example: the reader armed with this knowledge will be able to distinguish quickly between a true crystal (quartz) ball, of the kind used for crystal-gazing or for ornament (which if large and flawless may be of considerable value), and one of the comparatively worthless spheres of glass which are commonly sold as substitutes. If the corner of a card be placed immediately behind a quartz crystal ball and viewed through it, a ghostly double image of the edge of the card can be seen in most positions. On rotating the ball it will be noticed that the doubling effect is more pronounced first on one edge and then on the other, while in one direction through the ball (along the optic axis of the original quartz crystal) no doubling will occur. In the case of a glass ball the edges of the card will appear single in all directions. A little practice will do more than any

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amount of reading to beget competence and confidence in using the test. Once these 'doubling' effects have been clearly seen and understood, they will be found quite easy to observe, and of great practical value in the discrimination of precious stones.

Figure 12. Photomicrograph of zircon taken through table facet showing doubling of the back facets

It is worth noting that, when scrutinizing with a lens a brown or deep green tourmaline or a brown sphene, the expected doubling of the back facet edges may not be apparent. The reason for this is that in the stone mentioned, one of the two rays may be totally absorbed. This is an extreme example of the effect known as *dichroism*, which will be considered in the next chapter.

COLOUR, COLOUR FILTERS, AND THE DICHROSCOPE

It has often been stressed by those who write about gems that colour is a most unreliable guide in identifying a stone. Such a statement is, of course, to a certain extent true, and the tendency in the past to label (with qualifying adjectives) all yellow stones as topaz, all red stones as ruby, and all green stones as emerald was due to too great an insistence upon the importance of that usually accidental* characteristic, colour. Anyone, however, whose job is to handle and appraise coloured stones knows how a really practised eye can recognize a number of the well-known gems at once by their characteristic shade of colour. Ability to recognize the particular shades exhibited by a given variety can be acquired by anyone with a naturally good colour sense and developed by practice to quite an astonishing degree of virtuosity. As an instance of this the author can remember, when showing a case of about fifty mixed coloured stones to a group of gemmology students at Chelsea Polytechnic, that one of the students was able to name correctly every specimen at sight, with the exception of one or two rarities.

Such knowledge and acute perception of colour are admittedly rare, but for the normal person even if the species still remains in doubt the colour of the stone will have narrowed down the possibilities, especially when the lustre is also considered.

Thus, though there are many 'green' stones, several 'red' stones, and several 'blue', there are few indeed that have the green of emerald, the red of ruby, or the blue of sapphire.

Against this it must be admitted that the more brownish red tints seen in Siam rubies are almost impossible to distinguish from certain red garnets and spinels, and that among the pale pink or mauve stones it is very hard for the eye to distinguish between pink topaz, tourmaline, mauve spinel, pale amethyst, kunzite, and pink beryl. Often two stones which appear to have precisely

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* 'Accidental', because the majority of the gem minerals would be colourless if they were chemically pure compounds, and owe their varied hues to traces of certain metals which act as colouring agents. (See Glossary, under Allochromatic and Idiochromatic Minerals.)

similar colours can be distinguished on a colour basis if these colours are analysed or sorted by simple instruments.

To understand how this can be so, we must make a very brief incursion into theory. What we call 'white light'—that is light from the sun or other incandescent bodies—is composed of a mixture of all the colours of the rainbow. For this reason a circular card painted in equal sectors with the bright rainbow colours will appear white while spinning rapidly.

Newton, in the year of the Great Fire of London (1666), was the first to show that sunlight has a composite nature, by analysing a narrow beam which passed through a chink in the shutter into his darkened room by the simple expedient of placing a glass prism in the path of the ray.

Light is variously refracted by a transparent solid according to its wavelength, the red rays, of longer wavelength, being less deviated than the shorter, violet, waves. Thus these rays, having been deviated by different amounts, on passing through the prism were separated, and could be seen to fall upon a screen as overlapping patches of pure colour—in fact what we call a spectrum band of colours—red, orange, yellow, green, blue, and violet merging imperceptibly into one another.

Now some stones appear coloured to the eye simply because they absorb some of the white light when it passes through them, and some wavelengths (colours) are more strongly absorbed than others. This is known as 'preferential absorption'. Those colours which are least absorbed pass on to the eye and mingle to form what we call the 'colour' of the stone. Actually the colour was in the original white light and has not been created by the stone, which has merely robbed the white light of the colours complementary to those we see. It is a fact that two stones may absorb quite different sets of wavelengths from white light and yet present precisely the same colour effect to the naked eye so long as what we may call the 'mean effective wavelength' of unabsorbed colours is the same in each case.

The spectroscope (which analyses light in a manner similar in principle to Newton's original experiment) will often reveal this difference in the 'make-up' of two similar colours, and thus provide us with a beautiful means of identifying coloured stones. The use of this valuable instrument may be outside the scope of the average jeweller, but anyone who wishes to enlist its aid will find

a clear description in Chapter 8. A similar and often very effective means of revealing underlying differences in colour is by use of suitable 'colour filters'. These are especially successful in discriminating between emerald and its imitations.

Emerald is almost alone among green stones and glasses in transmitting an appreciable amount of deep red light and absorbing to some extent the yellow-green portions of the spectrum. Many emeralds also emit a deep red fluorescent glow when strongly illuminated. When viewed through a coloured filter which transmits only deep red and yellow-green light, an emerald will appear distinctly red, whereas most of the imitation emeralds or real stones resembling emerald retain their green appearance through the filter. Many such filters have been marketed in Britain and on the Continent, but by far the most successful is the 'Chelsea' filter, developed in the Precious Stone Laboratory of the London Chamber of Commerce and at the Chelsea Polytechnic. The Chelsea filter has other uses besides the separation of emerald from its counterfeits, but the user is apt to draw false conclusions unless he bears in mind carefully the various possibilities, as sometimes 'red through the filter' is a danger sign and in other cases it is a sign that all is well. A careful perusal of what follows should prove helpful.

Green Stones. Most emeralds, as already stated, appear red through the filter varying from a fine ruby-red with stones of good colour to pale pink with paler emeralds. Some emeralds, notably those from South Africa and India, show practically no colour change. On the other hand, green glass imitations, most green doublets, green tourmaline, and green jadeite retain a greenish colour through the filter. Demantoid garnet and green zircon give a pinkish effect, and so do some specimens of stained green chalcedony, but these are sufficiently unlike emerald in ordinary light to cause little confusion. Unfortunately, some types of 'soudé emerald' triplets show a distinct red, and a reddish tinge may be seen in emerald-green fluorspar.

Blue Stones. Materials coloured with cobalt blue transmit a considerable amount of deep red light and appear red through the filter. Thus blue synthetic spinels and blue cobalt glasses show a tell-tale red colour which assists in distinguishing these counterfeits quickly from sapphire, aquamarine, or blue zircon, which appear a dirty green. It must be noted, however, that many Ceylon

sapphires contain a trace of chromic oxide; these appear purple in artificial light and show distinctly red through the Chelsea filter. Natural blue spinels also show a reddish tint but in neither of these natural minerals does the colour approach the full-blooded red seen with deep blue synthetic spinel.

Red Stones. The filter is not of much help here, but the bright fluorescent red effect seen when Burma and synthetic rubies are viewed through the filter is worth noting. No other red stone shows quite this appearance.

To obtain the best results with the Chelsea filter, hold the stones close to a strong artificial light and view them through the filter held close to the eye so as to cut out any extraneous glare.

DICHROISM AND THE DICHROSCOPE

The colour coming from a gemstone may be composite in another sense from that already described. In almost all doubly refractive coloured stones there are *two differently tinted rays* reaching the eye
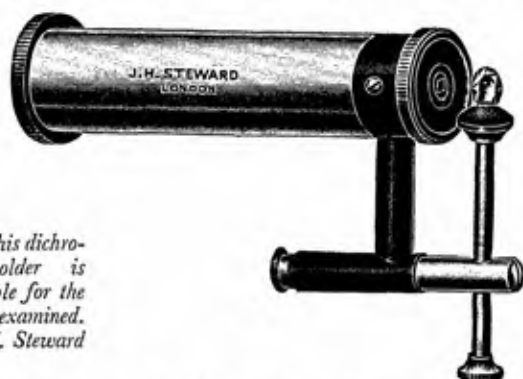

Figure 13. In this dichro-scope the holder is readily adjustable for the gem to be examined. Made by J. H. Steward

together, inextricably mingled. The fact that a stone is doubly refractive means in general that rays travelling through the stone in a given direction are of two kinds, one vibrating in one plane and the other in a plane at right-angles to the first. Not only are these rays as a consequence of their different vibrations travelling with different velocities (hence the effect of double refraction) but they usually suffer a *different colour absorption*. This effect is known as 'dichroism' ('two-colour effect') or, more generally, 'pleochroism' ('many-colour effect'), since some stones show three colours, though there can be only two in any one direction.

The effect cannot be seen with the unaided eye except by turning the stone in different directions and noticing the change in tint that strongly dichroic stones may show according to the direction in which light traverses the crystal.

To see *both colours at once* as they come from a stone, we use a simple little instrument called a dichroscope (Figure 13). This is in its essentials merely a tube with a window at one end and a lens at the other; in between there is mounted a piece of calcite so chosen that it causes (by its strong double refraction) two images of the window to appear side by side as the observer looks through the eyepiece. Now light from these adjacent images of the window
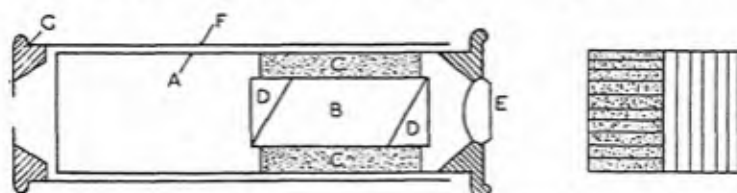
Figure 14. Construction of dichroscope. A is a metal tube fitted with a rhomb of calcite B, in a cork setting C, and an eyepiece E. Prisms of glass D are cemented to the calcite to enable the rays to be directly transmitted. The tube A slides into another tube F fitted with a rectangular 'window' G. On the right of the diagram is a representation of the two images of the dichroscope window as seen through the eyepiece

is vibrating in two planes at right-angles to each other, one plane for each image. By holding a coloured stone in front of the window of the dichroscope, so that light passes through the stone into the instrument, we are able to see side by side the colours appropriate to each of the two polarized rays from the stone (see Figure 14).

Usually it is merely a matter of a different depth of tint of the same colour—sapphire, for instance, commonly shows dark blue and light blue (Oxford and Cambridge) respectively in the two windows, but in some stones amazing differences in colour are seen; e.g. in Siberian alexandrite the colours purple, green, and orange may be seen (two at a time) if the stone is turned in front of the dichroscope.

Turning the stone is indeed an important factor in testing for dichroism. In all doubly refracting stones there are either one or two directions of single refraction, known as optic axes, and in these directions there can be no dichroism. This is well known, but it is not so commonly realized that in other directions also no dichroism will be visible if the vibration directions of the two

images of the aperture happen to be at 45° to those of the two rays from the stone.

An important point to note is that the mere fact that dichroism is seen assures the observer that the stone is doubly refracting and therefore not a paste or a cubic mineral. Thus we have another test for double refraction (see Chapter 4). Ruby can be distinguished from red spinel and garnet, blue spinel from blue tourmaline of similar shade, sapphire from blue synthetic spinel and so on. Descriptions of the dichroic colours for the various stones are given in books, but even stones of the same kind vary a good deal and the effects are best learned by experience. When the effect is faint it is difficult to be sure that the imagination is not providing the supposed difference in tint.

For the observation of dichroism daylight is the best illumination. Hold the stone up to the light in corn-tongs, using the left hand, then observe it through the dichroscope held in the right hand, using it as you would a short-focus lens. The 'window' of the instrument is small, and beginners find it difficult to place the stone exactly in front and at the same time to get sufficient light through the stone to enable them to judge the colour effects. Most instruments are fitted with a weak magnifying lens as eyepiece, and two slightly enlarged images of the stone, or part of the stone should be seen, one in each image of the 'window'. Only one or two facets as a rule will be transmitting enough light to see the colour, but with even only a small patch of colour in each image, one can readily compare the two tints seen and observe any differences of colour.

As already stated, the stone should be viewed from a number oı different positions to ensure that the maximum effects are seen. In a well cut ruby, in which the optic axis should be perpendicular to the table facet in order to get the best colour effect, little dichroism should be seen when viewed through the table. In a synthetic ruby, the peculiar colour of which is often partly due to the fact that it is wrongly cut from the point of view of colour, the dichroism as seen through the table is usually strong.

The more expensive types of dichroscope are fitted with a holder on which the stone can be fixed and easily rotated in front of the window of the instrument. This makes observations more easy for the beginner to carry out, but is not, of course, essential for good results.

If a transparent piece of Iceland spar 1 in. or more in length is available, a 'dichroscope' of a kind can be constructed merely by gumming a piece of black paper on to one end of the spar and scraping a small hole in the paper. The only skill required is in making the hole of such a size that the two images of it produced by the double refraction of the spar are contiguous.

Polaroid film can also be pressed into service in various ways. For instance, the specimen may be placed on a sheet of white paper in a good light and observed through a Polaroid disk. If the dichroism is at all strong a colour change will be clearly noticeable when the disk is rotated.

Beautiful dichroic effects can be seen in such rather rare stones as violet-blue iolite from Ceylon, green andalusite from Brazil, blue apatite from Burma, sphene, and benitoite. Better-known gems in which dichroism is strong or distinct include ruby, sapphire, alexandrite, most tourmalines, kunzite, blue aquamarine, and blue zircon. In such stones the change of colour due to dichroism when they are turned and viewed from different directions is quite apparent to the unaided eye, and skill in discerning dichroism by this kind of direct observation is well worth cultivating.

The keen gemmologist may find that the dichroscope provides more interest and yields more information if the vibration directions of the light coming from each image of the 'window' is known. This can easily be ascertained by experiment, and marked once and for all on the rim of the eyepiece. One way of determining the vibration directions is to look through the dichroscope at light reflected from a polished desk or table. Such light is largely polarized, and its vibration direction is parallel to the reflecting plane. The dichroscope image which is the brighter of the two will be that transmitting rays which are vibrating parallel to the table, while the vibration direction of rays from the darker image of the window will be at right-angles to this.

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THE SPECIFIC GRAVITY OF GEMSTONES
AND HOW TO MEASURE IT

EVERY jeweller knows by experience that some gemstones 'weigh heavier' than others: that, for instance, a white zircon weighs more than a diamond of equal size and a sapphire more than an emerald. Scientists long ago provided a precise definition for this quality of 'heaviness', which provides a valuable means of distinguishing one substance from another when worked out on a numerical basis. This was done by taking water as a standard and comparing the weight of each substance with the weight of an equal volume of pure water. The figure thus arrived at is called the 'specific gravity', 'relative density', or simple the 'density' of the substance in question. The specific gravity of a body, then, is simply the ratio of its weight to that of an equal volume of pure water. For accurate work, water at 4° C is specified as the standard.
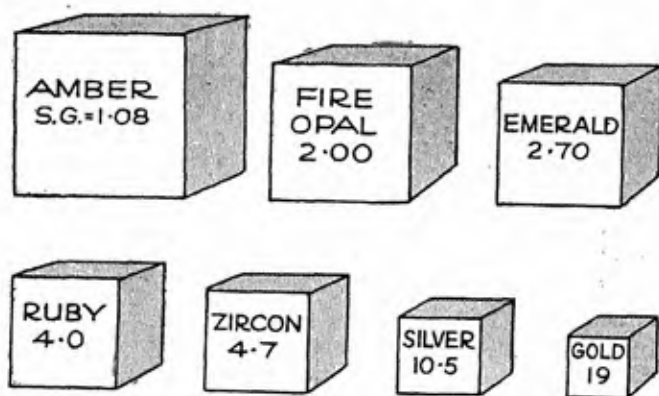
Figure 15. This diagram gives the size in each case of 50 carat weights if they were made from cubes of amber, fire opal, emerald, ruby, zircon, silver, or gold

Thus, when we say the specific gravity of aluminium is 2·7 and that of ruby 4·0, we mean that, bulk for bulk, aluminium weighs 2·7 times, and ruby 4 times, as much as water.

Materials used in jewellery show a very wide range in density,

from amber, 1·08, to platinum, 21·5. The diagram (Figure 15) shows what would be the relative sizes of cubes of equal weight made from amber, fire opal, emerald, ruby, zircon, silver, or gold.

At the end of the chapter will be found a list of the specific gravities of the substances of most importance to the jeweller, and it will be recognized that if this property can be easily determined (and it can), it will provide a very sure means of distinguishing one species of stone from another.

Provided the stone to be tested is free from any kind of setting, (and admittedly this proviso implies a serious limitation for the jeweller) the method is universal in its application—be the stone rough, faceted, carved, cabochon cut, large or small, its density may be determined by one method or another, and without the use of expensive apparatus.

In saying 'without the use of expensive apparatus' one is assuming that every jeweller has a good diamond balance on the premises as part of his essential equipment. For accurate determinations by the first method to be described below, the balance should be in perfect order and the weights really accurate.

This last condition is not by any means common, owing to the continual wear and tear entailed in the use of the weights, and on the other hand their gain in weight if allowed to become dirty. Simple and often revealing tests are to balance one two-carat weight against the other, then both two-carat weights and the one-carat against the five-carat weight, and finally all these together against the ten-carat weight. If all these balance evenly, as they should, there is probably little wrong with the weights used.

An ordinary diamond balance may be readily adapted for measuring the density of a stone by employing a principle which was stated by the Greek mathematician, Archimedes, about 250 B.C., and is thus known as 'Archimedes' Principle'. This principle states that bodies when immersed in a liquid are buoyed up by it with a force equal to the weight of the displaced liquid. This means that when (say) a gemstone is suspended in water it will apparently suffer a loss in weight equal to the weight of the water it displaces. Obviously the gem displaces its own volume of water, and thus, simply by weighing a stone first in air and then immersed in water we have all the data necessary to calculate its specific gravity (abbreviated = S.G.).

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For, by definition, $\text{S.G.} = \dfrac{\text{Weight of stone}}{\text{Weight of equal vol. of water}}$, and

this, as we have seen, may also be expressed:

$$\text{S.G.} = \dfrac{\text{Weight of Stone}}{\text{Loss of weight in water}}$$

The weight of the stone is, of course, determined in the usual manner; to determine the weight of the stone in water some simple contrivances are necessary.

First: a small bridge or stool must be arranged to straddle over the left-hand balance pan in such a way that the free swing of the balance is unimpeded. Such a bridge can be cheaply bought at chemical supply firms, or it can be easily made by an amateur carpenter. An effective improvisation is to place a match-box upright on either side of the pan with a thin strip of wood, such as a 6-in. protractor rule, acting as a bridge between the boxes. Upon this bridge is placed a beaker (or a small tumbler), some three-quarters full of distilled or boiled water. Using copper wire of fairly heavy gauge (about 1 to 1·5 mm) make a spiral coil in which a stone of any size from about 2 to 30 carats can comfortably rest, and suspend this from the lower hook of the balance arm by a much finer wire of copper, brass, or (best of all on account of its tensile strength) tungsten, of such a length that the coil which is to hold the stone is well immersed in the water, yet not touching the bottom of the beaker. If it is too much trouble to make a separate heavy cage supported by a finer wire, a simpler procedure is to use one piece of brass wire just thick enough to be sufficiently stiff (about 0·5 mm), coiling one end into a spiral and bending the other end into a loop to fit over the balance hook (see Figure 17). Since a coarse wire impedes the free swing of the balance to a serious degree for accurate work, the finer the suspending wire the better, so long as it is strong enough to stand the strain of a few ounces. Tungsten wire of only 0·05 mm will do this.

All is now ready for the experiment.

The stone must be weighed in the ordinary way very accurately, estimating, if possible to the third decimal place (in carats). Then, having the bridge and vessel of water in position, the stone is placed in the wire spiral and suspended in the water: it is then

weighed while thus immersed. Then, with the stone removed, the spiral alone is weighed while immersed as before, and this weight subtracted from the combined weight of stone and spiral in water. We now have the data we need (weight of stone in air and in water) to work out the S.G. by the formula already given.

It may be preferred to have the wire spiral immersed in the water throughout all the weighings, counterpoised exactly with another piece of wire (or any suitable weight) in the other pan.

Figure 16. Arrangement
of balance for specific
gravity test
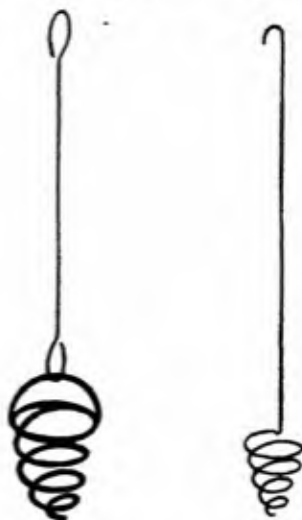
Figure 17. Spiral coils of wire
in which stones can be rested for
the hydrostatic weighing test

Then no allowance for the wire need be made, but the free swing of the balance will be somewhat impeded for the weighing in air.

It is important to *see that no air bubbles are clinging to the wire or the stone when immersed in water.* Fresh tap-water contains a lot of air; thus, to avoid trouble it is better to use distilled water or water which has been boiled and subsequently cooled. A camel-hair brush (ordinary water-colour brush) is useful in this connection. Immerse the wire cage in the beaker of water before placing it in position on the balance and, having thoroughly wetted and squeezed the brush itself to get rid of any air trapped between the hairs, gently rub over the wire coil with the brush until no air

bubbles can be seen. Then, if the stone is first thoroughly wetted by dipping in water and rubbing with the fingers no bubbles should be present when it is placed in the cage. The presence of a few air bubbles may make a difference of several hundredths of a carat to the weighing and vitiate an otherwise accurate result. If the bubbles were on the cage and could be guaranteed to 'stay put' during the whole operation, and if the total weight of the cage (bubbles and all) could be allowed for, it would not matter, but bubbles are unreliable things and may become dislodged half-way through the experiment.

To illustrate the working of the method, here is an actual example. A red stone, weighing 7·535 carats, was thought to be a garnet on account of its colour and the fact that it showed no dichroism. A refractometer was not available, so the specific gravity was measured by the above method (which is called the method of 'hydrostatic weighing').

The weight of wire cage and stone immersed in water proved to be 12·196 carats, and the wire cage alone in water weighed 6·753. The weight of the stone in water was therefore

$$12 \cdot 196 - 6 \cdot 753 = 5 \cdot 443.$$

The loss of weight in water shown by the stone is thus

$$7 \cdot 535 - 5 \cdot 443 = 2 \cdot 092.$$

Using the formula $S.G. = \dfrac{\text{Weight of stone}}{\text{Loss of weight in water}}$

we have $S.G. = \dfrac{7 \cdot 535}{2 \cdot 092} = 3 \cdot 602.$

This stone was therefore not a garnet but a *red spinel*, since a garnet of the almandine-pyrope series of this colour would have a density near 3·80.

Results obtained by hydrostatic weighing are less accurate for small stones than for large, and for stones of equal weight results are less accurate for stones of high density than for those of low density, as their volume is smaller. It is easy to calculate what effect in the final result a given small error in the 'weighing in water'

will have. Supposing a density determination be attempted on two Siam rubies, one weighing eight carats and the other weighing only one carat, the true density in each case being exactly 4·00. For an identical error of 0·01 carat in the 'weighing in water' the final result will be 4·02 in the case of the larger stone—not a very serious matter—but 4·16 with the smaller stone, which is so high as to make one suppose that the stone must be almandine garnet and not ruby.

Now when using water the error of 0·01 carat in the immersion weight postulated above is quite possible, since the high surface tension of water tends to vitiate the even swing of the balance owing to the drag on the suspending wire where it cuts the surface of the water. Hence the desirability of a very fine wire. Further, the formation of tenacious bubbles on wire or stone is also an effect of the high surface tension. A single drop of liquid detergent or of one of the 'wetting fluids' supplied by photographic dealers added to the water will help matters considerably. But if it is desired to obtain the best possible results with small stones (say under 3 carats) it is advisable to use not water but some other fluid having a lower surface tension. Toluene and ethylene dibromide are two stable and fairly inexpensive liquids which can be recommended for the purpose.

It is of course essential when using such fluids to multiply the result in the simple formula by a factor representing the density of the fluid used at the temperature of the experiment, thus:

$$\text{S.G.} = \frac{\text{Weight of stone}}{\text{Loss of weight in liquid}} \times \text{Density of liquid at } T° \text{ C}$$

Even when using water this factor should strictly be used, since the density of water is only exactly unity at 4° C. But the value for water is so little below this, even in hot weather (e.g. 0·998 at 70° F) that this correction can be safely disregarded in ordinary determinative work. The density of the pure liquids can be obtained from tables, but in practice these vary slightly from sample to sample, and it is wise to check the density of each batch (which will last for years if kept in a stoppered bottle), a task which is quite simple if one proceeds as follows:

Take a large specimen of pure quartz, say 30 or 40 carats, and carry out a careful density determination with this in the liquid

which you wish to check. Then, knowing that pure quartz has an invariable density of 2·651, calculate the density of the liquid thus:

$$\text{Density of liquid} = 2 \cdot 651 \times \frac{\text{Loss of weight in liquid.}}{\text{Weight of stone}}$$

The temperature of the liquid should be noted, and the densities at other temperatures can then be safely assessed by *subtracting* 0·0007 for each 1° C rise in temperature in the case of toluene and 0·002 for each 1° C rise in temperature for ethylene dibromide. The usual densities for the two liquids at 60° F are, toluene 0·870, ethylene dibromide, 2·188.

When hydrostatic density measurements are going to be carried out frequently it is worth while to prepare a table giving the density of the liquid used for each degree centigrade (for each tenth of a degree for really accurate work) with the appropriate seven-figure logarithm alongside. The calculation can then be quickly made by logs, and the whole job be finished in less than ten minutes.

HEAVY LIQUID METHODS

It often happens that only an approximate value for the density of a specimen is required, to differentiate between stones of similar appearance, such as topaz and yellow quartz, chrysoberyl cat's-eye and quartz cat's-eye, etc. In such cases a very rapid density test can be made by the use of **heavy liquids.**

In principle, the 'heavy liquid method' is exceedingly simple.

Obviously a stone will sink in a liquid less dense than itself, float in one that is denser, and will remain suspended in a liquid having an equal density. Provided, therefore, that one can obtain a series of suitable heavy liquids it is clear that by placing the stone under test in liquids of different known densities and observing whether it sinks or rises to the surface, one can quickly arrive at an estimate of its density.

Before giving practical details for the employment of this method, let us consider what liquids are suitable. Some ten fluids have been proposed from time to time, but of these, three only need concern us, as they cover the necessary range and are the most convenient in use.

Firstly there is *bromoform*, a mobile, slightly yellowish liquid with

a density of 2·9. Secondly, *methylene iodide*, mobile and yellow when fresh, density 3·33, and thirdly, *Clerici solution*, colourless and rather viscous, density 4·15.

The first two are organic liquids, and will mix in any proportions with benzene, toluene, or alcohol, all of which have a density of less than 1·00; thus by diluting bromoform or methylene iodide with any of these, their density can be lowered to any desired extent. Clerici solution is conveniently so called after its discoverer, an Italian chemist. It consists of a concentrated aqueous solution of two thallium salts, the malonate and formate, and the density of this solution can thus be readily lowered from its maximum value of about 4·15 by simply adding a little distilled water.

After mixing or diluting one liquid with another, it is essential to stir thoroughly with a clean glass rod. This is particularly necessary in the case of the viscous Clerici solution.

Methylene iodide and Clerici solution are rather expensive, but since only small quantities are required and they last a long time this does not greatly matter.

Heavy liquids can be kept, pure or diluted to a definite density value, in small cylindrical specimen tubes about ¾ in. × 3 in., securely corked and placed in holes bored in a block of wood.

The number of liquids kept ready for use and their density values must depend upon individual needs. Here are some suggestions derived from the author's own use of heavy liquids for all manner of gemstones:

1. Bromoform diluted to 2·65.
2. Bromoform diluted to 2·71.
3. Methylene iodide diluted to 3·06.
4. Methylene iodide, pure, 3·33.
5. Clerici solution diluted to 3·52.
6. Clerici solution diluted to 4·00.

The bromoform and methylene iodide, as already stated, can be diluted with toluene or one of several other liquids of low density. The Clerici solution must always be diluted with distilled water; tap water will do, but the liquid may tend to cloudiness if this is used, and as Clerici solution is expensive it is worth while taking a little trouble to keep it in a clear condition.

If the density of the liquids is inadvertently made too low by

dilution, it can of course be raised by addition of the pure liquid or, in the case of Clerici, of the concentrated solution. A dilute solution of the latter can also be readily reconcentrated by careful evaporation with or without heat.

To obtain a liquid of density 2·65, a small fragment of quartz or small cut stone of the quartz group such as amethyst, citrine, or rock crystal is placed in a tube about half filled with pure bromoform, and toluene then added drop by drop, accompanied by continuous stirring with a glass rod, until the specimen acting as an 'indicator' just begins to sink or only rises very slowly if pushed below the surface with the rod.

One then knows that the liquid has a density of 2·65, and the indicator can be kept in the tube to enable the user to check the density of the solution each time it is used, since this may vary owing to one constituent evaporating more rapidly than the other. The second liquid (2·71) proposed is similarly prepared, using a small piece of calcite (Iceland spar) as indicator.

The third liquid (3·06) is prepared by diluting methylene iodide until a small piece of green tourmaline remains suspended; the fourth liquid is simply pure methylene iodide and if kept uncontaminated needs no indicator.

For the fifth suggested liquid (3·52) concentrated Clerici solution is diluted with drop after drop of distilled water (stirring thoroughly after each added drop of water) until a small diamond used as indicator remains practically suspended in the liquid; and finally the liquid of density 4·00 is similarly prepared, using as indicator a small specimen of synthetic ruby.

If the Clerici solution as purchased contains a deposit of solid thallium salts, a little distilled water can be added and the whole be brought into solution by careful warming in a vessel containing hot water.

The process of matching the liquids exactly with the density of the specimens is decidedly a tricky one and requires skill and patience, but so long as the indicator rises or falls in the liquid only slowly this is a sufficiently close match to enable a pretty accurate idea to be obtained of the density of the liquid in question, which of course is the purpose of the indicator.

Many workers prefer to employ two indicators in each liquid, one of which should remain floating and the other stay at the bottom of the tube. It is then known that the density of the liquid

lies between those of the two indicators. This is quite sound so long as the two indicators are so chosen that their densities are close to one another. If their densities lie too far apart only a very rough idea of the density of the liquid is possible.

It must be emphasized once more that the six liquids listed above are merely suggestions which can be varied according to the type of testing the user is most likely to want to carry out. The jeweller with little time to spare can learn a great deal by the intelligent use of three liquids only—pure bromoform, pure methylene iodide, and Clerici solution reduced to 4·00 by the suppliers, and thus save himself the trouble of making any mixtures. The pure liquids will need no indicators, since the pure bromoform can be reckoned as 2·9 and the methylene iodide 3·33 at ordinary room temperature and partial evaporation will not affect these densities.

A few strips of copper kept in the bottle or tube of methylene iodide will serve to prevent it from darkening as the copper combines with the free iodine which is the cause of the trouble. The clarity of a dark sample can also usually be restored by shaking it with a liberal supply of copper scrap and leaving it in contact with the metal for some days before filtering it off into a clean bottle.

It is wiser not to test porous stones such as American turquoise or opal in heavy liquids as they may be harmed. Stones with flaws which reach the surface may also suffer in appearance if immersed in liquids. Stones and tongs should be cleaned after use in a heavy liquid test and before being passed from one liquid into another, since any liquid adhering to the stone would alter the density of the next solution it enters. This rule is particularly important when using Clerici solution, as this being an aqueous mixture does not mix with any of the other liquids. After a Clerici immersion, stone and tongs should be rinsed with water and dried; in the case of the other liquids benzene is perhaps the best cleanser.

Minerals in which the specific gravity is most constant are those with simple chemical compositions, such as diamond, quartz, and corundum. Apart from lapis lazuli and turquoise, which are not properly homogeneous, there are three gemstones which show large variations in density: these are zircon, red garnet of the almandine-pyrope series, and blue spinel. The zircons used in

modern jewellery, that is to say the blue, white, and golden stones mined in Indo-China and heat-treated, cut, and shipped from Siam, have a constant density of near 4·69. Certain green zircons from Ceylon, however, may have a density of 4·00 or even lower, and a whole range of densities is found in Ceylonese stones between these limits.

The reason for this extraordinary variation was first established by Chudoba and Stackelburg in 1936. It is due to a breakdown in the crystal lattice: zircons of lowest density being almost completely amorphous. (See Chapter 14.)

The red garnets, the density of which may range from 3·68 to 4·20, owe this variation to their being mixtures of two minerals of different composition and properties: pyrope garnet, which is a silicate of magnesium and aluminium, and almandine garnet, in which the magnesium is replaced by iron.

Pure pyrope and pure almandine are not known, but stones with densities up to about 3·85 and refractive indices up to about 1·76 are usually classed as pyropes, while the denser stones are known as almandines.

The author has proposed the name 'pyrandine' as a convenient term to describe garnets which are intermediate between pyrope and almandine.

Blue spinel normally has a density near 3·60, but zinc sometimes replaces part of the magnesium, raising the density markedly without affecting the colour or appearance. Values of 3·70 or 3·80 are not very uncommon, while 3·98 was recorded in one exceptional case.

One great advantage of using heavy liquids compared with the hydrostatic method is that results are just as reliable with very small stones as they are with large specimens. Further, a number of stones can be tested at one time; for instance, a parcel of small emeralds can be checked for any 'duds' by pouring the stones into a liquid of density 2·71. Any stones which sink or rise at all rapidly can be taken out with the tongs and regarded with grave suspicion, their true nature being determined by other means. True Colombian or Siberian emeralds will either rise or fall quite slowly in such a liquid. South African emeralds are rather denser, but in any case will not sink fast.

As a test for synthetic emeralds a liquid matching the density of quartz (2·651) is useful, since Chatham emeralds have a density

very near to this, while all natural emeralds will sink with some rapidity in this liquid.

For distinguishing amber from its imitations among the plastics, such as Bakelite, Erinoid, etc., a liquid which can hardly be termed 'heavy' must be employed. According to R. Webster, ten level teaspoonfuls of cooking salt in a tumbler of water will make a brine solution sufficiently dense to float amber, while the various plastics so far used to imitate amber are all decidedly denser and will sink in this solution.

Although heavy liquids are mostly used by gemmologists to obtain only an approximate value for the density of a specimen, the method can be extended, by taking a little trouble, to measure the specific gravity of a stone with considerable accuracy. If one of the liquids be carefully diluted until an exact match is reached with the stone to be tested, that is, so that no perceptible rise or fall of the specimen in the liquid can be noted, then one may be quite sure that the density of the stone and the liquid is the same (*at that particular temperature*) to at least the third place of decimals. If, therefore, one can accurately measure the density of the liquid, the density of the stone is also known. This can be done by filling a small 'specific gravity bottle' with the liquid and carefully weighing. Then if the weight of the empty dry bottle and its weight when filled with water are also ascertained the comparative weight of the bottleful of the liquid and of the water will give one the density of the former.

A more rapid, but not quite so accurate, method of finding the density of a heavy liquid is by using a small hydrometer. For this a fair quantity of liquid is needed, and it is thus chiefly useful for the bromoform series. The author has found a small hydrometer, giving the range 2·5–3·0, particularly useful. Such hydrometers have to be made specially, the cost being about ten shillings. T. O. Blake, London, is a skilful maker of these instruments.

Another useful accessory is a set of glass indicators, each marked with its appropriate density; these can be supplied by Messrs Rayner & Keeler, London. Alternatively, a set of indicators can be made with very little trouble or expense from small specimens or pieces of those minerals which are readily procurable in a pure state and can be relied on to have a constant density. In the following brief list of suitable materials the figures given for those in heavy type can be taken as correct to the second place of

decimals provided transparent flawless pieces are chosen. The others may vary by as much as $\pm$ 0·02, but this does not greatly vitiate their usefulness as indicators..

Quartz (rock crystal)	2·65
Calcite (Iceland Spar)...	2·71
Tourmaline (pink)	3·05
Fluorspar (transparent)	3·18
Peridot	3·34
Diamond	3·52
Topaz (colourless)	3·56
Chrysoberyl (yellow)	3·72
Demantoid garnet	3·85
Corundum (synthetic white)	3·99
Sphalerite (transparent)	4·09

Another very rapid and convenient method of estimating the density of a heavy liquid is to measure its refractive index on a refractometer, and then to read off its density value from a previously prepared graph. This is very readily done in the case of Clerici solution. Samples vary slightly in their properties, but the graph reproduced here is quite representative, and should certainly give results quite accurate enough for identification pur-

Figure 18. Graph giving relation between refractive index and density of Clerici solution

poses. Being a straight line graph, it can be extended *ad lib.* by the use of ordinary graph paper.

A table of density values for the more important gemstones and certain metals and other substances handled by the jeweller is given below. The figures are those found by the author to be most characteristic for the substances named, but for the sake of simplicity the range of variation found is in most cases not given. This is usually quite small, and where the density is given in the table to two places of decimals the variation is generally confined to a few units in the second decimal place.

Where there is a wider variation the density is quoted to only one place of decimals.

The more important gem materials are printed in capitals.

AMBER	... ...	1·08	Fluorspar ... ... 3·18
Bakelite	... ...	1·26	Spodumene ... ... 3·18
Tortoiseshell	... ...	1·29	*JADEITE* ... ... 3·33
Erinoid...	... ...	1·33	*PERIDOT* ... ... 3·34
Celluloid	... ...	1·38	Sinhalite ... ... 3·48
Vegetable Ivory	...	1·40	*DIAMOND* ... ... 3·52
Ivory ...	... ...	1·80	*TOPAZ* (Pink) ... 3·53
Bone ...	... ...	2·00	,, (Yellow) ... 3·53
Fire Opal	... ...	2·00	,, (White) ... 3·56
OPAL ...	... ...	2·10	Sphene ... ... 3·53
Obsidian	... ...	2·40	*SPINEL* ... ... 3·60
Moonstone	... ...	2·57	,, (Synthetic) ... 3·63
Chalcedony (Agate,			Hessonite ... ... 3·65
Cornelian)	... ...	2·60	*PYROPE* ... 3·7–3·8
QUARTZ	... ...	2·65	*CHRYSOBERYL* ... 3·72
Coral ...	... ...	2·68	*DEMANTOID* ... 3·85
BERYL (Aquamarine)		2·69	*ALMANDINE*... 3·9–4·20
,, (Yellow)	...	2·69	*CORUNDUM* ... ... 3·99
,, (Emerald)	...	2·71	*ZIRCON* (Green) 4·0–4·5
,, (Pink)...	...	2·80	,, (Blue, White,
PEARL (Oriental)	...	2·71	Golden) ... 4·69
,, (Cultured)	...	2·75	Pyrites ... ... 4·90
Turquoise (American)		2·70	Haematite ... ... 5·10
,, (Persian and			Silver ... ... 10·50
	Egyptian)	2·80	Gold, 9 carat... ... 11·40
Lapis Lazuli ...	...	2·80	,, 14 carat... ... 13·93
Pink (Conch) Pearl	...	2·85	,, 18 carat... ... 15·40
Nephrite	... ...	3·00	,, 22 carat... ... 17·70
TOURMALINE	...	3·05	,, Pure ... ... 19·30
Andalusite	... ...	3·15	Platinum ... ... 21·50

The foregoing list will certainly cover all the materials handled by the average jeweller. For the benefit of keen gemmologists or collectors who are interested in the rarer gemstones, a more comprehensive table is given at the end of the book.

6

DETECTION OF SYNTHETIC AND IMITATION STONES*

In the earlier chapters it has been shown how it is possible by simple tests to assign any gemstone that is in common use in jewellery to its correct mineral species. If, by refractive index or other tests, we have determined a stone to be, say, a peridot, a zircon, or a topaz, there is the end of the matter so far as identification is concerned. Knowing certainly its nature, estimation of the stone's value can then be made on the basis of colour, purity, perfection of cutting, and weight. But where the stone tested turns out to be a ruby or a sapphire or an emerald, then a further problem still awaits solution, as every jeweller knows: namely, is the stone natural or synthetic? In experienced hands the answer may often be easily arrived at: sometimes, however, there are no readily apparent signs of distinction, and laboratory tests may be needed to settle the issue. Probably in no other branch of gem testing is there so great a disparity between the amateur gemmologist and the professional laboratory worker, with his skill, born of long experience, in interpreting correctly the small signs which differentiate between natural and synthetic stones. By careful study of the following pages the reader will at least know what to look for, and the accompanying photomicrographs should also prove helpful. But plenty of practice will be needed with actual specimens if any real skill is to be obtained.

By 'synthetic' stones we mean man-made stones having the same composition, crystal structure, and properties as the corresponding natural minerals. Corundum (ruby, and sapphires of different colours) is the only gem mineral in large-scale commercial production which accords at all strictly to the above definition, though synthetic emerald is now entering the market in increasing quantity. Synthetic spinels are also widely used, but to represent stones of other species than their own: they also have significant differences in composition, properties and colour from

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* As already mentioned in the first chapter, the surest way of distinguishing synthetic from natural stones is by examining them under a microscope. The present chapter should thus be read in conjunction with the description of the microscope which follows.

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natural spinels. Synthetic rutile and the new strontium titanate (which is not found in nature) are also described in this chapter, but are not so commercially important.

RECONSTRUCTED RUBIES

The earliest artificially produced gemstones to reach the market were the so-called 'reconstructed' rubies which first made their appearance in 1882. These first emanated from a village near Geneva, but were later made by several skilled practitioners in different centres, including Hatton Garden, London.

Figure 19. Typical bubble cloud in synthetic ruby

The methods used probably differed considerably in detail, but were alike in fusing or sintering together small chips of inferior natural ruby added to the main mass one by one under the hot flame of an oxy-hydrogen blowpipe. The result was a small button-shaped boule, not unlike those first made by the Verneuil process (see under) but, in some cases at least, with a fragment of natural ruby still adhering to the narrow part of the mass. One might expect such stones to consist of small randomly oriented blocks—and stones showing the expected discontinuities have been described and photographed by Dr E. Gübelin. In this country

we are far more familiar with reconstructed stones in which there has been complete integration of the original components. It has been claimed that such stones are merely early Verneuil synthetics, cut from the base of a boule, but we are convinced that this is not the case. The curved striae in these stones are heavily marked, steeply curved, and not strictly parallel. At a casual glance, they resemble much more closely genuine Burma rubies than do the modern synthetics: the colour is richer and 'softer', and the swarms of included bubbles may give the effect of 'silk'.

Only the keen gemmologist will be interested in distinguishing between reconstructed rubies and synthetic rubies: the average jeweller, once that he knows that a ruby is not genuine, will not wish to be bothered with such nice distinctions. Nevertheless, the practice of calling all synthetic stones 'recos' is to be deprecated—especially in the case of sapphires, since to these the technique of reconstruction from natural stones was never successfully applied.

THE VERNEUIL PROCESS

All previous methods for making synthetic rubies were superseded, and the era of commercial synthetic gemstones began, when the French scientist Verneuil designed his special furnace, which incorporated an inverted oxy-hydrogen blowpipe or 'chalumeau'. The Verneuil process has since been successfully used not only in the preparation of ruby and sapphire corundums of many other colours, but also of spinel, rutile, and strontium titanate, as will be described below.

Certain of the features, such as curved growth-lines and included gas bubbles, which we rely upon for distinguishing Verneuil corundums from their natural counterparts, arise essentially from the nature of the process by which they are grown. It may therefore be useful to give here a brief description of the essentials of the Verneuil method.

Purity of the solid raw materials and of the oxygen and hydrogen used in the blowpipe flame is most important. Alumina, the essential constituent of corundum, is derived from ammonium alum, which is a double sulphate of ammonium and aluminium containing water of crystallization, crystallizing in octahedra. The alum is recrystallized to ensure purity, and later calcined in large crucibles at 1100° C. The alum decomposes with evolution of

ammonia, sulphur dioxide, and water vapour, leaving a residue of pure alumina in the unstable 'gamma' form, as a very fine powder. When ruby is required, up to 8 per cent chromic oxide is added to the original batch of alum before calcination, and the calcined product then has a pale green colour. For blue sapphire oxides of iron and titanium are added to the alum; for yellow sapphire, nickel oxide; for 'alexandrite'-coloured corundum, vanadium oxide is added, and so on. The powder is placed in a sieve at the top of the furnace and, after the gases have been lit, this is periodically tapped with a small hammer, which results in small controlled quantities of powder falling through the flame, where the powder melts and falls as white-hot droplets on to an inch-wide pipeclay pedestal beneath the flame, which is enclosed in a circular chamber. A conical mass of small corundum crystals is first formed. The flame is then so adjusted that a small single rod begins to grow in the centre of the mass, gradually swelling as the supply of powder is increased into the familiar boule form— a domed cylinder of some ¾-in. width, tapering to a narrow base. Corundum boules have a strong tendency to split lengthways, and are always so split, if necessary by nipping them with pliers, to release the strain before they are cut or fashioned for use as gems or in industry.

Stones analogous to natural spinel are also grown in similar fashion, the raw materials here being alumina and magnesia, with cobalt oxide added for the popular shades of blue, manganese oxide for pale green stones, and iron oxide for those of pale pink shade. It has been found that where the ratio of alumina to magnesia used is 1 : 1, as in natural spinel, the boules do not grow successfully. The most favourable ratio is $3\frac{1}{2}$ alumina to 1 magnesia. The resulting boule consists of a mixed crystal of spinel and 'gamma' alumina, with which it is isomorphous. The tendency of the cubic 'gamma' form of alumina to revert to the stable trigonal 'alpha' form (corundum) gives rise to strain within these synthetic spinels which, in consequence, always show an anomalous birefringence when examined between crossed polarizers.

Typical examples of corundum and spinel boules are shown in Figure 20. Whereas corundum boules do not commonly show any crystal form, spinel boules have flattened sides which correspond to crude crystal faces of the cubic system. The upper surfaces of the boules are frosted with tiny crystals formed during the rela-

tively rapid cooling which takes place when the furnace gases are switched off. These, too, differ in the two cases. In corundum boules the surface, when examined with a lens, will be seen to consist of tiny overlapping rhombohedral platelets, rather resembling tiles on a roof, whereas on spinel boules are seen chains of linked octahedra intersecting at an angle of 90°.

(a)   (b)

Figure 20. (a) Corundum and (b) spinel boules

The curved lines of growth, which are commonly seen only in coloured synthetic corundums, are due to the intermittent fall of the droplets on to the boule's upper surface, and to the greater volatility of some of the colouring oxides compared with alumina, which causes minute differences in colour and refractive index as one layer is succeeded by another. The gas bubbles seen in so many synthetic corundums consist almost certainly of hydrogen, of which an excess is used in the furnace gases. The gas may be occluded in particles of the falling powder, and thus incorporated in the boule. In synthetic blue sapphires there are generally curved bands of colour broad enough to be observed by the naked eye—especially when the stone is immersed in a suitable liquid and observed against a white background. In synthetic ruby and other coloured synthetic corundums the growth-lines are much finer and when magnified they resemble the lines on a gramophone record. The actual *growth-lines* in blue sapphire are in fact as fine

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as this, as we have found by using the technique described below: normally, however, only the broad swathes of colour are visible. In all cases it should be realized that growth-lines are only visible when the stone is viewed in the correct orientation (corresponding to directions at right-angles to the length of the original boule) and under suitable lighting conditions. It can thus be understood that with mounted stones there may be great difficulty in detecting these valuable diagnostic features. The nature of the curved lines in synthetic ruby and sapphire are well shown in Figures 25 and 27, respectively.
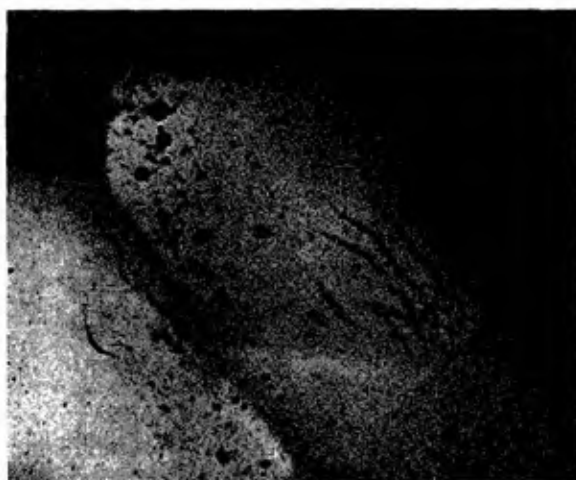
Figure 21. Bubbles and cracks in synthetic ruby

Recent experiments in the author's laboratory have shown that 'immersion contact' photographs of synthetic stones may often reveal curved growth-lines in synthetic corundums when these are invisible under lens or microscope when viewed in the same orientation. This fact may be of considerable practical value in certain cases. The general technique has already been described in Chapter 2 as a means for determining refractive index. When used for revealing delicate features such as the growth-lines in synthetic corundum the conditions have to be somewhat stringent. The immersion liquid has to match the corundum closely in refractive index, and the beam of light passing through the specimen on to the film below should be narrow and nearly
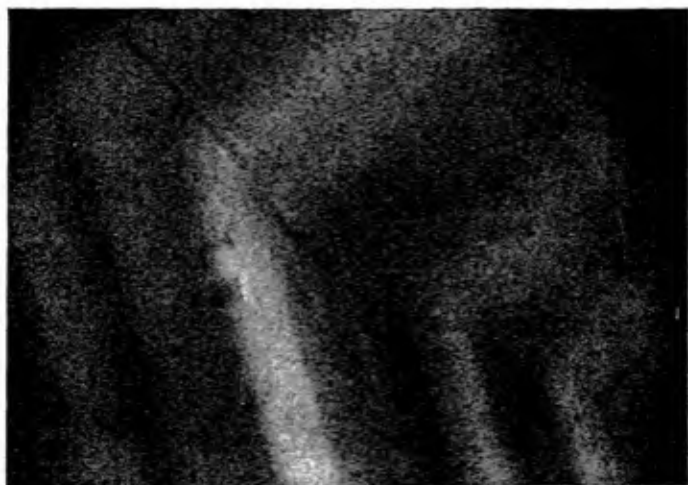
Figure 22. Zoned colour bands in natural sapphire

Figure 23. Inclusions in Burma ruby

parallel. Fortunately, pure methylene iodide serves very well for the immersion fluid, as it has very nearly the same index as corundum for blue and violet light, which are the operative colours for the slow film used. If a photographic enlarger is available, light from this, with the lens stopped down to f/22, provides a very suitable illumination for the process. Under these conditions, curved growth striae have been observed even in colourless synthetic corundum, together, it must be admitted, with straight lines making an acute angle with these, the origin of which is not yet understood. Although curved lines may be made visible by this method at angles other than the optimum, the orientation must not be too far wrong. Large synthetic stones are normally cut with their table facet parallel to the length of the original boule, and as a consequence the lines should be visible at right angles to the table—a fact very convenient for the technique outlined above. Yellow synthetics fail to show these lines.

In contrast to the curved layers of growth seen in synthetic corundums, any lines or bands of colour seen in natural rubies are rigidly straight, as they follow the outlines of the original crystal, which invariably has flat faces. Moveover, such lines or bands in natural stones can frequently be seen to meet each other at angles of 120°, since they are parallel to the outlines of a hexagonal crystal. The gas bubbles which are a feature of synthetic corundums are never seen in natural stones. On the other hand small crystals of minerals associated with corundum in nature, such as zircon, rutile, spinel, mica, haematite, or even other crystals of corundum itself, are usually to be seen when the specimen is scrutinized under a low-power microscope. Tiny flat cavities containing liquid are also a common feature of natural stones. These are usually assembled together in the same plane, either flat or slightly curved, forming what is commonly known as a 'feather'. Rubies and sapphires from different localities each tend to have their own characteristic inclusions. Only in Burma rubies, for instance, does one find the patches of slender, short, rutile needles, intersecting at angles of 120°, which, from their appearance in reflected light, are known as 'silk'. And only those corundums which come from Ceylon show included zircon crystals surrounded by crack-like halos. More will be said concerning these and other features in natural rubies and sapphires in the appropriate chapters. There are, however, certain further

distinguishing features peculiar to synthetic corundums which should be given here.

Small, roughly parallel crack-like markings are often seen at or near facet junctions in synthetic corundums. Lapidaries call these 'fire marks', and they are caused by local overheating during the polishing process. These are only seen on corundum, and are only indicative of a synthetic stone because in these less care is taken to avoid such blemishes. Another feature which only serves as an indication is the strong dichroism usually visible when a synthetic ruby is observed through a dichroscope at right-angles to its table facet. In fashioning natural rubies the lapidary usually grinds his table facet at right-angles to the so-called optic axis of

Figure 24. Contact photograph of synthetic and six natural rubies showing greater transparency of synthetic ruby to short-wave ultra-violet light

the crystal, thus ensuring the best colour for the stone. When this is done, no dichroism will be visible through the table. Thus, strong dichroism in this direction is a suspicious sign, since it points to a synthetic ruby, which is randomly cut.

More stringent 'extra' tests for synthetic rubies are available for those with laboratory facilities. In the first place, it has been found by the author and others that synthetic rubies are decidedly more transparent to short-wave ultra-violet light than are natural rubies. The presence of traces of iron in the latter is probably the main factor governing this difference. A determination on these lines is possible without the use of expensive apparatus if one calls immersion contact photography to one's aid, as first suggested by Mr Norman Day.

Stones to be tested are placed, table facet down, on a sheet of photographic paper which is immersed in a flat-bottomed dish of water to a depth sufficient to cover the rubies. This must be done, of course, either in a dark-room or in a room which is nearly dark. The stones are then exposed for a few seconds to light from a short-wave (2537 Å) ultra-violet lamp held some eighteen inches or so above the dish. On developing the paper, provided the exposure time has been correct, the images of natural rubies will appear white (showing their relative opacity to the rays) whereas synthetic stones appear dark, except for a marginal white rim. An example of this rather spectacular test is seen in Figure 24. It has been found that Kodak 'Velox' printing paper gives better results in this method than the faster bromide papers or than photographic film.

Where a suitable X-ray plant is available another test may be used in those cases where the microscope does not easily yield the required information. Both natural and synthetic rubies show a bright red fluorescence under X-rays, but when the radiation is switched off there is a pronounced after-glow with synthetic stones, whereas in natural rubies no after-glow can be detected. To be effective, this test should be carried out in a darkened room, and with the observer's eyes 'dark adapted', in which condition they are far more sensitive to the rather feeble red after-glow it is required to detect.

In the case of corundums of other colours, the spectroscope may often be of great assistance in distinguishing between natural and synthetic stones. Natural green sapphires, for instance, show a g oup of three absorption bands in the blue part of the spectrum, merging into one another to form what at first glance may appear to be a single broad band. No bands of this kind are seen in synthetic green corundum. What is far more important in practice is that in most natural *blue* sapphires the strongest at least of the three bands mentioned (wavelength 4500 Å) can almost always be detected. Again, this is missing in synthetic sapphires, so that when seen it forms a sure test for natural sapphire. The same is true for yellow sapphires from Siam, Australia, or Montana. In yellow sapphires from Ceylon there may not be enough iron present to produce any absorption bands, but in these there is a distinctive apricot-yellow fluorescence under long-wave ultra-violet rays. Yellow sapphires showing neither absorption bands

nor fluorescence are almost certainly synthetic. Finally, in those synthetic corundums coloured by vanadium which are intended to represent alexandrite, there is a very distinctive narrow line in the blue at 4750 Å, while alexandrite chrysoberyl has an entirely different spectrum of its own (see Chapter 8).

A word more ought to be said about the gas bubbles which have been merely mentioned as being typical for stones (particularly corundums) manufactured by the Verneuil flame-fusion method. Bubble-shapes in synthetic stones and in glass are well worth study,
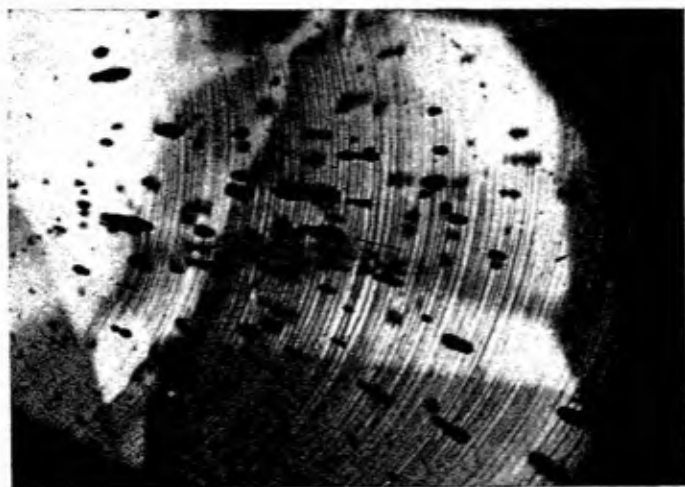
Figure 25. Curved lines and bubbles in synthetic ruby

since they vary a good deal with the nature of the medium. It is also important to be able to distinguish the small rounded crystal particles found in many natural stones from bubbles of rather similar appearance. In synthetic corundums the smaller isolated bubbles are usually almost perfectly spherical, but where little groups or 'bubble clouds' are encountered some of the shapes are nearly always distorted, and there may be amalgamation into 'clots', which sometimes present an unexpectedly 'natural' appearance. Extreme elongation into hose-like forms is also possible, and confusing to the beginner. Larger individual bubbles, usually only encountered near the base of the growing boule, are often flask- or bomb-shaped in outline, the direction of apparent

Figure 26. *Straight colour-bands in natural sapphire*
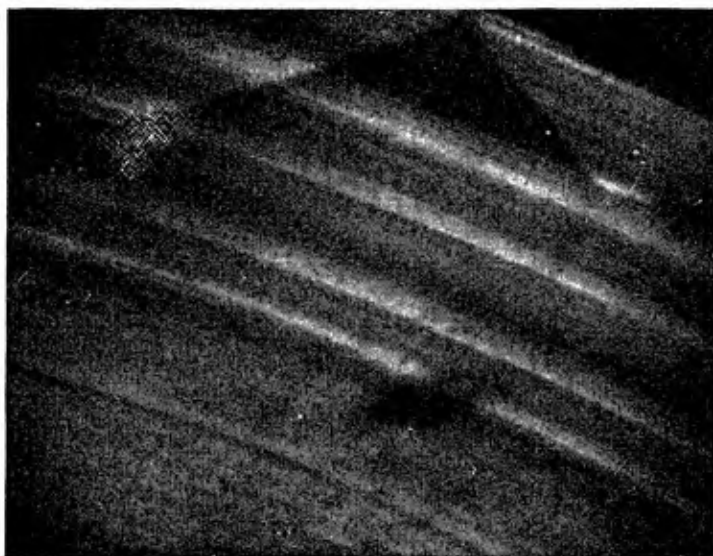
Figure 27. *Curved colour-bands in synthetic sapphire*

'fall' of these bombs being at right-angles to the curved layers of growth, as the bubbles are trapped on their way towards the surface. Bubbles in synthetic corundum are also sometimes enclosed in flat triangular cavities, which may present a misleadingly 'natural' appearance to the beginner.

SYNTHETIC STAR CORUNDUM

In 1947 there were released a series of star sapphires and star rubies, which were made by preparing boules with a small proportion of titanium in addition to the usual colouring agents, and annealing these for periods of two to seventy-two hours at temperatures ranging from 1100 to 1500° C. Under this treatment the titania crystallized out as short, fine crystals of rutile, oriented at angles of 120°, in accordance with the structure of the corundum crystal lattice. Stones cut en cabochon with the axis of the cabochon coincident with the optic axis of the corundum showed a brilliant six-rayed star by reflected light. Thus the Verneuil process surprisingly entered a field where it was thought that Nature must remain unchallenged.

The synthetic star-stones can usually be recognized at sight. The star effect is very brilliant, almost as though it were 'painted on' to the outside of the stone. The colour of the synthetic stones is also brighter than the natural star corundums, which seldom combine good colour with a sharply defined star. The neatly ground-off base of the synthetics is distinctive, and there is an absence of the zoning seen in almost all natural star corundums. Bubbles are usually present in great numbers, as well as curved bands of colour. The stones vary from sub-transparent to nearly opaque. In the opaque types one must look for bubbles immediately below the surface, the stone being illuminated from above.

SYNTHETIC SPINEL

As already mentioned above, synthetic spinels of a kind are also made by the Verneuil process. These were originally made accidentally in the early years of the century in an endeavour to colour synthetic corundum blue by addition of cobalt, using magnesia as a flux. But it was not until the mid-twenties that synthetic spinels were made on a large scale. They are not made in colours associated with natural spinel, but usually in tints suitable for
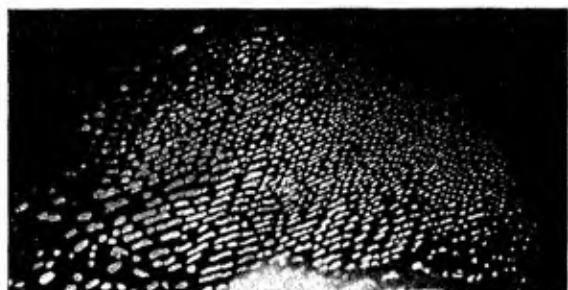
Figure 28. Liquid 'feather' in Ceylon sapphire

Figure 29. 'Silk', zircon, and other inclusions in Burma ruby

counterfeiting blue zircon, aquamarine, alexandrite, sapphire, or even diamond. All these stones have quite different properties from spinel, and thus, however convincing their appearance may be, distinction is easy by a number of orthodox tests, and the microscope is seldom called into play.

This is just as well, as (except in the red variety, which has only recently been manufactured) curved structure lines are hardly ever to be seen, and the majority of stones are free from bubbles. Both these facts are due to the relatively slow growth of the boules: the same lack of growth lines and bubbles is noticeable in yellow synthetic corundums which (according to Prof. W. F. Eppler) are also usually grown slowly. When bubbles do occur in synthetic spinels they may assume very bizarre forms, though tiny isolated spherical bubbles are sometimes encountered. Distortions include long, hose-like tubes, often oriented in parallel formation; large 'profilated' bubbles, like bulky furled umbrellas or long flasks made by an inexpert glass-blower. These last have been shown by Dr E. Gübelin often to assume in part the shapes of negative crystals, roughly hexagonal when viewed end-on, and these may further be grouped in a hexagonal pattern in planes at right-angles to the trigonal axis of the boule lattice, providing a very 'natural'-looking feature to the eye of a beginner.

A. J. Breebart recently described two-phase inclusions which he was the first to notice in synthetic spinel. These consist of tiny flat cavities containing a bubble and either liquid or gas, often joined by a thin tube to a similar flat cavity parallel and below the first. Tiny, emaciated, comma-shaped bubbles are also sometimes seen in synthetic spinels. All these variations in bubble-shapes are extremely interesting to the keen gemmologist, but it is perhaps fortunate that so many other features in synthetic spinel provide an easy means of recognition.

As already remarked, the composition of synthetic spinel is markedly different from the natural, in containing a considerable excess of alumina. This has an effect on its physical properties, raising the refractive index to a figure which never varies more than one unit in the third place of decimals from an average of 1·727. Natural spinels, unless they contain zinc, lie within the range 1·715 to 1·720. The density of synthetic stones is 3·63 or 3·64, as against 3·58 to 3·60 (again excepting the rare zinc-rich types of blue spinel in which both density and refractive index may rise

considerably). Another character induced by the excess alumina, under strain in its tendency to revert to corundum, is a marked anomalous birefringence, resulting in a very characteristic appearance between crossed polars for which the author coined the term 'tabby extinction'. This can be seen in Figure 30. It is well worth
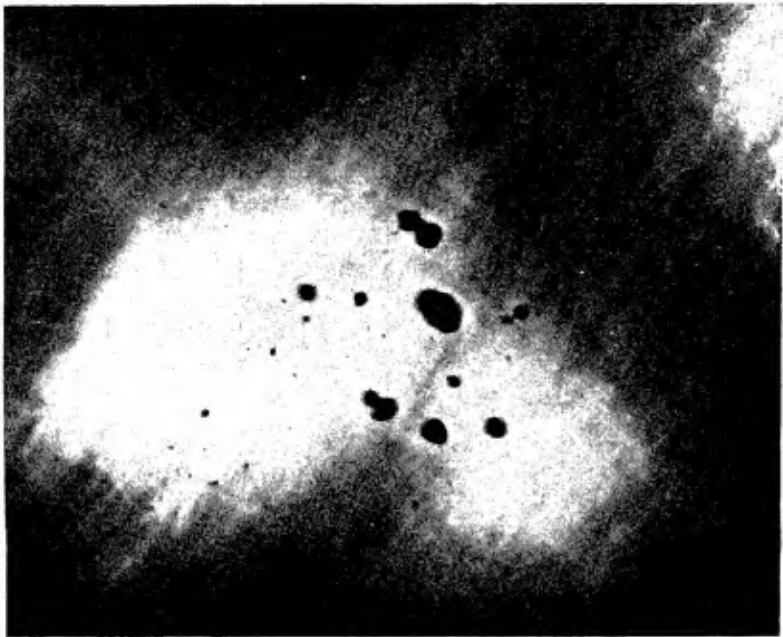
Figure 30. Synthetic spinel between crossed polarizers, showing 'tabby extinction' and profiled bubbles

remembering this particular feature when struggling to identify small, colourless baguettes of synthetic spinel mounted, as they often are, as a substitute for diamond in pieces of jewellery. Immersion of the whole in methylene iodide may reveal, by the lack of relief, that the stones are not diamond, but the tabby extinction will confirm the stones as synthetic spinel where they might otherwise be possibly synthetic sapphire or a highly refractive glass.

The Chelsea colour-filter and the spectroscope also play a useful part in the identification of synthetic spinel, especially the very popular blue types used to imitate aquamarine, etc. These are coloured with cobalt in almost all cases, and the absorption in the

yellow-green and clear transmission in the deep red characteristic of cobalt blues result in the stone assuming a strong red colour through a Chelsea filter. Natural blue spinels may appear somewhat reddish through the filter, but are hardly likely to be confused with the synthetics in any case, as their daylight colour is so different a shade of blue.

With the spectroscope, blue synthetic spinels show three broad absorption bands due to cobalt. In the pale blue stones made to represent aquamarine these are quite faint, while in the deep blue stones resembling sapphire they are strong, and so broad as almost to amalgamate into a single wide band extending from the orange to the green. These dark blue stones give out red gleams by reflected light, which serve to reveal their nature to the naked eye. Usually, a little chromium is added to the stone to improve the colour, and this gives rise to a red fluorescence under ultra-violet light or between crossed filters.

Other coloured varieties of synthetic spinel are used less frequently. An attractive pink type resembling morganite beryl is produced by addition of iron and a pale yellowish green type by using manganese as colouring agent. These have a strong green fluorescence under ultra-violet light and two absorption bands in the violet. Synthetic spinel resembling alexandrite in colour and showing a perceptible colour-change in artificial light can be made, but is very seldom seen. It has, of course, no dichroism, and this fact, together with its lower, single refractive index, make distinction from alexandrite chrysoberyl easy. But so far as sheer appearance goes, this variety of synthetic spinel is far more deceptive than the synthetic sapphires coloured with vanadium which are so commonly met with.

Colourless synthetic spinel is very clear and bright, and utterly devoid of colour. Athough in figures its dispersion of 0·020 between the B and G lines of the solar spectrum is very little greater than the 0·018 of corundum, there is perceptibly more 'fire' than in the latter, and it has often been used to represent diamond, particularly in baguette form, where its inferiority in lustre and fire to diamond are not so readily apparent as when cut as a brilliant. Immersion in methylene iodide and examination between crossed Nicols has already been suggested above as a simple means of identification.

Although synthetic red spinels can be made by the Verneuil

process, it is only recently that these have appeared in any quantity on the market, but small stones are now available and are even cheaper than synthetic ruby. In these the ratio of magnesia to alumina must be nearly the same as in natural spinels. They are chrome-rich—entailing a saturated red colour and rather high refractivity (1·725), with specific gravity 3·60. Under the microscope curious curved swathes of colour are plainly seen, together with clouds of small gas bubbles. The stones are red-fluorescent, but do not show the same 'organ-pipe' fluorescence lines as natural spinels do through the spectroscope, the light being concentrated mainly in a line at 6850 Å.

A milky white variety of synthetic spinel has been another recent production. This is made by annealing the ordinary colourless synthetic, the milkiness (sometimes with asterism) being due to incipient separation of corundum. Stones are cut en cabochon to resemble moonstone.

A granular, nearly opaque, cobalt-blue form of synthetic spinel has been produced by a sintering process as a substitute for lapis lazuli. This is fully described on page 256.

A few examples have been encountered, however, of synthetic red spinels which have not been made by the Verneuil process. We know this, not only by their lack of Verneuil-type inclusions and their peculiar properties, but by the discovery by gemmologists in the U.S.A. of a large octahedral crystal of this type of red spinel, firmly implanted on a metal disk. The origin of these things, and the process by which they were made can only be guessed at. Though singly refractive, their refractive index has been found to vary in different parts of the stone from about 1·73 to 1·76, while the density is also very high (3·7 to 3·9). These freak stones remain a mystery. In appearance they resemble reconstructed ruby, but undoubtedly they are spinels of a kind, and not of natural origin.

SYNTHETIC RUTILE

Another product of the Verneuil flame-fusion method is that most spectacular of all synthetic stones—rutile. This caused a considerable stir on its first appearance in 1949, but has not been widely welcomed as a gem material, and has far less commercial importance than synthetic corundum, spinel, or even emerald. Rutile is well-known to the gemmologist as needle-like crystals included in ruby, and as larger needles in quartz—the so-called 'flèches

d'amour'. When found thus it has a typical red-brown colour, and crystals are seldom found in nature sufficiently transparent to warrant their being cut as gemstones.

Synthetic rutile is made in boules weighing about 200 carats in an oxy-acetylene version of the Verneuil blow-pipe, in an attempt to lessen the loss of oxygen which this compound tends to undergo at high temperature, with consequent darkening of colour. As it is, the boules are completely black and opaque when they leave the furnace, and have to be treated by heating to around 1000° C in a stream of oxygen before they have any ornamental value. During this treatment a variety of colours may be induced, rather unpredictably: but the makers' goal of a completely colourless rutile has not yet been achieved, a decidedly yellowish cast always remaining. An attempt to improve the 'whiteness' by adding strontium oxide has been partially successful, and stones which have been coated with a film of corundum to improve their surface hardness also seem to have a better appearance. Red, orange, blue, and brown rutiles have been produced by varying the after-treatment of the boules, and provide stones of spectacular beauty far preferable, in the author's judgement, to the off-white types which seem to be the only ones marketed—presumably in a vain attempt to rival diamond. Here, in brief, are the properties of synthetic rutile: Hardness, 6. Specific gravity, 4·25. Refractive indices, ordinary 2·61, extraordinary 2·90. Uniaxial positive, with birefringence 0·287. The dispersion (i.e. the difference in refractive index) between wavelengths 6708 Å and 4358 Å was found to be 0·2851 for the ordinary ray, which corresponds to approximately 0·300 for the standard range between B and G lines of the solar spectrum. The dispersion is thus some seven times greater than for diamond even for this ray, and must be higher still for the extraordinary ray. From the figure given above it will be realized that the double refraction, too, is enormous, being nearly five times that of zircon, and far greater even than that for Iceland spar, in which the double refraction of 0·172 is by normal standards reckoned very strong indeed.

Considering these properties, it will be realized that synthetic rutile can quite easily be identified without any elaborate tests. The stupendous 'fire' makes it as full of colours as a water-opal; the high refractive indices give it a high surface lustre, but with a 'soft' look compared with diamond, while the double refraction

causes a tremendous doubling of the edges of the back facets when viewed through the front of the stone. Clever lapidaries have learned to orient the stone so that the optic axis (direction of single refraction) is at right-angles to the table facet, thus mitigating the 'out-of-focus' appearance caused by the strong double refraction when viewing the stone from directly above. But when viewing the stone with a lens the slightest tilt will reveal the 'doubling' in great strength: far stronger than in the case of sphene, for instance, which is perhaps the only natural stone with which this synthetic could be confused.

One other feature of synthetic rutile may be mentioned in conclusion: there is a strong absorption band in the violet, beginning at about 4250 Å. The presence of this band probably accounts for the yellowish colour of the stone, and also for its high dispersion, since refractive index always rises steeply when a region of intense absorption is approached.

STRONTIUM TITANATE

Yet one more product of the flame-fusion method has recently appeared, and in this case a synthetic material has been produced which, so far as we know, has no natural counterpart in the mineral kingdom. The composition of this new synthetic stone is strontium titanate, $SrTiO_3$. It is thus analogous to the rare mineral perovskite, which is a calcium titanate having very similar properties.

Strontium titanate approaches more closely to diamond in its appearance and its optical properties than any other material, natural or synthetic. It is practically colourless, it is cubic, and therefore single refracting, and its refractive index is 2·41, and therefore practically equal to that of diamond. The dispersion is approximately four times that of diamond, giving rise to a play of colour noticeably in excess of that shown by diamond, but not so extravagant as that seen in rutile. The density is high (5·13) and the hardness low (about $5\frac{1}{2}$); this latter fact providing, one must admit, one of the best ways of distinguishing the stone from diamond when mounted in a setting. A steel needle, which is one of the most easily controlled 'hardness points' readily available, and one not likely to do much damage, will be found to mark the surface of strontium titanate, while of course it leaves diamond entirely unscathed.

Tiny inclusions, reminiscent of a centipede, or a ladder with bent rungs and no uprights, have been noticed by the author in several specimens of strontium titanate. No absorption bands have been observed, but complete absorption begins at about 4150 Å in the violet.

For those with the necessary equipment, the lack of fluorescence under ultra-violet rays or X-rays, and the opacity to X-rays will be useful signs distinguishing strontium titanate from diamond. The jeweller without equipment must be on his guard against any 'diamond' which shows an unusual degree of fire, and may resort
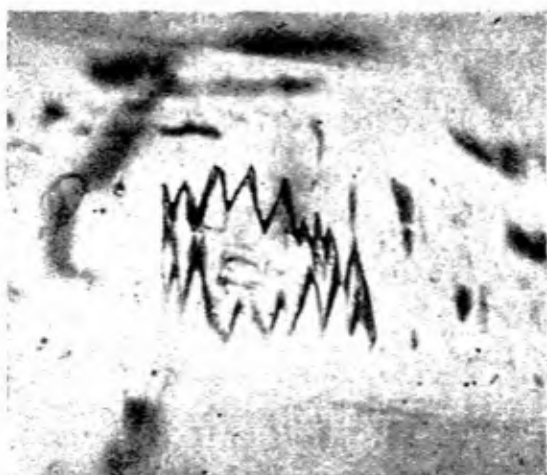
Figure 31.   Inclusions in Colombian emerald

to a careful test with a needle, as suggested above, or to testing the stone itself carefully against a piece of polished corundum, which only diamond will mark. If the stone should be free from its setting its high density will be revealed by its surprisingly high weight compared with its spread as measured on a diamond gauge.

SYNTHETIC EMERALD

The production of crystals of synthetic emerald in sizes large enough to be taken seriously was first achieved by chemists of the I. G. Farbenindustrie in Germany before the war. More recently, Carroll F. Chatham of San Fransisco has been making very similar

crystals from which some thousands of cut synthetic emeralds are now produced monthly. So far as one knows, the Chatham synthetic emeralds are the only ones on the market at the present time. The trained gemmologist should have no great difficulty in distinguishing these stones from natural emeralds, but they can cause considerable trouble to the dealer and jeweller who is not a specialist in such matters.

It is important at the outset to realize that synthetic emeralds are not manufactured by the Verneuil 'flame-fusion' process, and that one therefore must not expect such signs of synthesis as curved lines of growth or included bubbles. The precise method by which Chatham grows his emeralds is a closely guarded secret; but the

Figure 32. Surface structures on basal plane of synthetic emerald crystals

nature of the crystals and of the inclusions found within them make it clear that the process is a 'hydrothermal' one. The ingredients of beryl, together with the necessary chromic oxide to induce the rich green colour of emerald are contained in an electrically heated pressure chamber known as an autoclave. This is partly filled with water, sealed, and heated to above the critical temperature of water, thereby developing considerable pressure. Under such conditions the solid ingredients dissolve, and are slowly re-deposited as crystals in the slightly cooler upper part of the

autoclave. The process of producing crystals of useful size may take several months.

The synthetically produced crystals show a simple, rather squat prismatic habit with basal plane, very similar to those found in nature, though there is a tendency to form in clusters like sugar-candy, and for a number of parallel individuals to amalgamate, often leaving cavities of hexagonal outline in the direction of the main crystal axis. Parallel growth at a number of different centres may be revealed by low contoured markings as seen in Figure 32. The largest crystal so far made by Chatham is one of 1275 carats, which is in the Harvard Museum. This and several other large crystals are not of gem quality. Cut stones of over 6 carats are rarely seen, but specimens of 1–3 carats are now marketed in large numbers.

In appearance the synthetic stones have a rather characteristic saturated blue-green colour, which is to some degree distinctive, though Colombian emeralds of matching tint are sometimes encountered. Through the Chelsea filter they appear intensely red —distinctly more so than the majority of natural emeralds—and the same is true of their appearance between crossed filters, due to fluorescence.

The density of Chatham emeralds is distinctly low and remarkably constant, almost exactly matching that of quartz (2·651), so that diluted bromoform in which quartz is suspended as an indicator forms a very useful check for any loose emeralds suspected of being synthetic. Very few natural emeralds have a density below 2·70. The refractive indices and birefringence are also low; 1·560 and 1·563 being typical figures for the extraordinary and ordinary indices, giving a birefringence of only 0·003. The lower index in natural emeralds is from 1·570 upwards, with a birefringence of 0·005 to 0·006. A Rayner spinel refractometer is particularly valuable in enabling accurate readings in this region to be easily made in ordinary light—and for this test, of course, the stones need not be unmounted.

Such features are valuable as testing aids; but it is always possible that the manufacturer may so vary his ingredients as to raise both the refractive index and density of his products. The inclusions, which are the most reliable diagnostic feature, could not so easily be altered or controlled. In synthetic emeralds these consist of veil- or lace-like feathers, usually slightly curved, which are

quite unlike any features seen in natural emeralds. Under the microscope these feathers can be resolved into flattened liquid droplets forming an elaborate pattern, which can be well seen in the photomicrographs (kindly given to the author by Dr Edward Gübelin) which are reproduced in Figures 33 and 34. Transparent crystals of phenakite (beryllium silicate) are also frequently seen

(Photo: E. Gübelin)

Figure 33.   Typical pattern of liquid wisp-like 'feather' in Chatham synthetic emerald

in synthetic emeralds, and have not so far been observed in natural stones (see Figure 35). It is important for those who deal in emeralds to become familiar with their internal features: stones from each of the well-known localities show inclusions peculiar to themselves. In the chapter on emerald many of these will be found illustrated.

One other marked difference between synthetic and natural emeralds may be mentioned here as it provides a valuable laboratory test for distinguishing between them. It was discovered by the author (1953) that whereas emeralds from all known natural

sources are opaque to ultra-violet rays of wavelength shorter than 3000 Å, synthetic (Chatham) emeralds transmit short-wave light freely down to about 2300 Å. These results were first established by means of a small quartz spectrograph, but can be demonstrated much more cheaply and simply by the method proposed by Mr Norman Day, which has already been described as a means of distinguishing between natural and synthetic ruby.

The fact that synthetic emerald shows a red fluorescence under
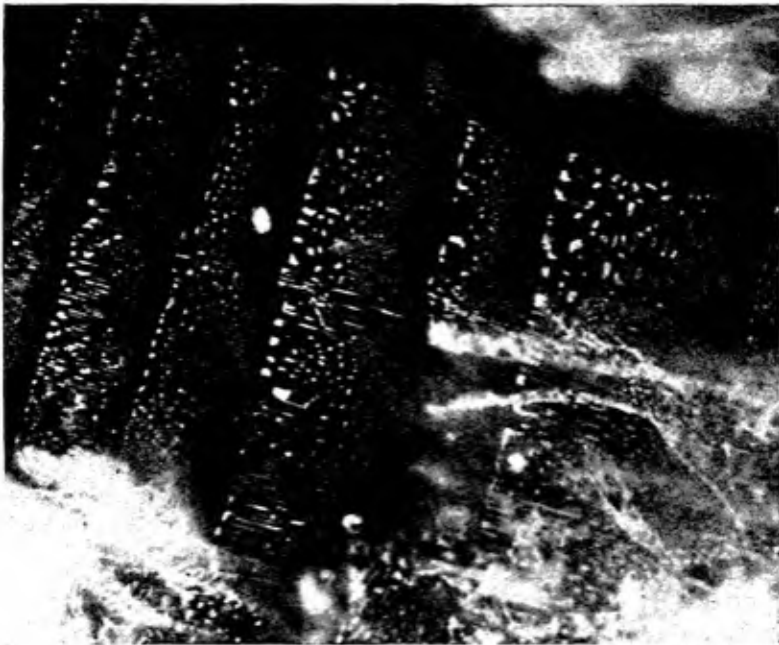
(Photo: E. Gübelin)

Figure 34. Parallel bands of liquid 'feathers' in synthetic emerald

long and short wavelength ultra-violet light has been claimed as a distinctive feature by some workers. Since natural emeralds of fine colour show very similar effects the method is not recommended by the present writer.

To sum up: when buying emeralds, jewellers and dealers should exercise caution. Stones of saturated bluish-green, showing a strong red colour when viewed through the Chelsea filter, should always be viewed with deep suspicion. If a refractometer is available, a low reading (below 1·570) would serve as a confirmatory test.

Wherever there is any doubt, stones should be sent for a laboratory test, where a definite decision can always be obtained on the basis of the methods outlined above.
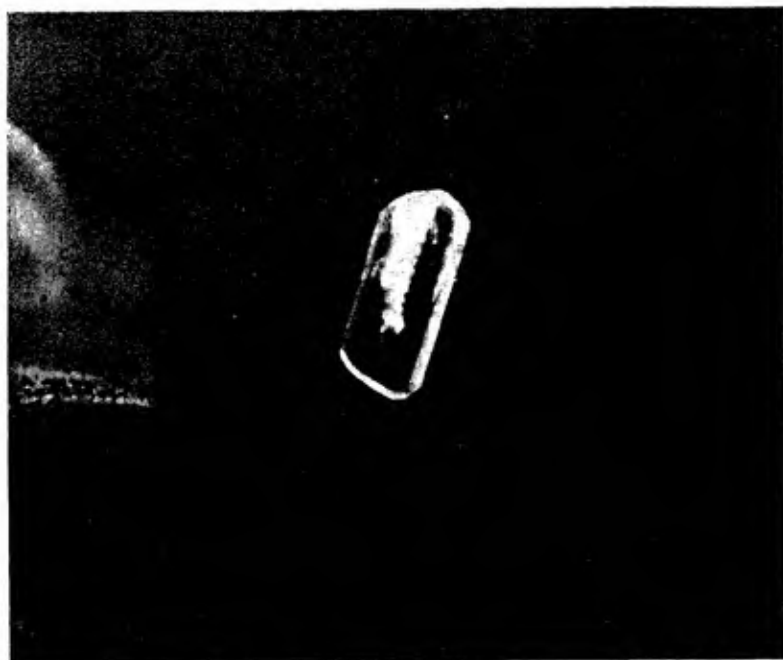
Figure 35.   Phenakite crystal in synthetic emerald

SYNTHETIC DIAMOND

For more than a hundred years scientists have striven, by all kinds of ingenious methods, to make diamonds by artificial means. Many, for the most part in good faith, have even claimed success. It was significant, however, that their experiments could never be repeated by other workers: often not even by themselves. Moreover there was no sound physical basis for supposing that, under the conditions obtaining, diamond, rather than graphite, would be the form of carbon produced.

During the past ten years or so the thermodynamic relations between diamond and graphite, which is normally the more stable form of crystallized carbon, have become increasingly clear. This

has been largely due to the researches in the United States of Prof. P. W. Bridgman, a physicist who has specialized in the production of very high pressures, and in the study of the effects of these on various forms of matter. In February 1955 the General Electric Co. of America released news of the successful assault on the problem of making diamonds by a team of workers in their research laboratories. In one series of experiments pressures of over 100,000 atmospheres (obtained by means of a giant hydraulic press) and temperatures of more than 2760° C were maintained in a very small pressure chamber, and in this very small crystals of diamond were produced from unspecified carbonaceous materials. It was possible to repeat these and rather similar processes with success a great number of times. The minute crystals obtained were stringently tested by X-ray and other methods, and proved to be indubitably true diamonds. The largest crystal so far claimed measures only 1·2 mm in length, and the manufacture of diamonds large enough and pure enough to be considered as gems is still far distant.

It is probable that, apart from diamond, these new high-pressure techniques will result in very interesting materials, some of them entirely new. One of these recently described is a boron nitride in cubic form, to which the name 'borazon' has been given. This is said to have a hardness equal to diamond. Hitherto only a soft, hexagonal form of boron nitride had been known, resembling graphite. The analogy with diamond thus seems very close.

GLASS IMITATIONS

Although the abundance of synthetic corundums and spinels manufactured by the Verneuil process has provided stones of vastly superior hardness to any glass imitations, the latter are still widely used, and are not always easy to detect at sight. So far as colour is concerned, glass can be made which matches most of the gemstones represented very exactly, and those stones which have a rather low refractive index have decidedly a vitreous (i.e. glassy) lustre, though their greater hardness enables them to take and to retain a higher polish than is possible with glass.

Jewellers were formerly accustomed to rely on a test with a hard file as an effective method for discriminating between real stones and glass imitations, but unless great care is taken damage

may easily be done even to genuine specimens by the use of this implement.

Better and safer methods are in any case available for detecting pastes, and some of these can now be listed:

1. *Warmth to the touch.*—Glass conducts heat less readily than most crystals, and thus feels warmer to the touch. The tongue,

Figure 36. Bubble and swirl marks in paste

being thin-skinned and always practically at blood-heat, is the most sensitive gauge of this property. The specimen should be cleaned and handled with corn-tongs (unless it is in a setting) to prevent it being warmed by the hand, which would vitiate the test. Direct comparison with a known crystalline gem makes a decision more easy. When properly carried out this is a very useful test.

2. *Conchoidal fracture.*—Glass is brittle and has a marked conchoidal fracture—that is, it breaks or chips in curved shell-like pieces, leaving shell-like concavities on the specimen. Examination with a lens of the edges of the specimen, especially where the claws of the setting (if any) bear upon it, will usually reveal some of these typical fractures. It must be said, however, that many gemstones also have a conchoidal fracture, though with these it is not so readily produced, nor on such a large scale.

3. *Bubbles.*—The presence of one or more comparatively large bubbles is a frequent feature in glass imitations, and, when seen, is a sure sign that the specimen containing them is not genuine.

With experience, one learns to distinguish between the bubbles seen in glass and those seen in synthetics of the Verneuil type. There are, of course, plenty of other distinguishing features between pastes and synthetics, but it is as well to be able to gain as much information as possible even from such humble things as bubbles. In pastes, bubbles are most often spherical and not grouped with others, but a pointed ellipsoid is very often seen, and this particular shape seems peculiar to glass alone. Sometimes chains or sheets of bubbles are found in paste and these in imitations of emerald help to give the illusion of natural flaws and feathers until they are closely examined.

Even in the translucent and semi-opaque glasses used to simulate jade, amber, or turquoise one can often detect bubbles just below the surface or circular cavities on the surface where bubbles have been partly polished away.

4. *Striae.*—Glass often contains curved striae or 'swirl marks', due to imperfect mixing of the ingredients. These striae are not so regular as the curved growth-lines in synthetic corundum. The effect is rather like that seen when sugar syrup is poured into water, and indeed is due to a similar cause—contiguous streams or layers of slightly different refractive index.

5. *Single refraction.*—Glass, being amorphous (non-crystalline), is always singly refracting, and thus shows only a single shadow-edge on the refractometer. Between crossed polarizers, however, glass may show irregular birefringence due to strain, and in rare cases may even show extinction positions at more or less regular intervals in the manner of crystalline gems, which is very disconcerting. Glass never shows dichroism, and since most coloured gems are dichroic this is often a simple means of distinction.

6. *Refractive Index and Density.*—In a glass imitation these constants are seldom the same as those of the stone represented. Some typical values for imitation gemstones will be found in the table below.

Colour		S.G.	R.I.	Type of Glass
Colourless	...	2·30	1·47	Borosilicate crown
Pale blue...	...	2·35	1·50	Borosilicate crown
Pale blue...	...	2·37	1·51	Borosilicate crown
Pale blue...	...	2·46	1·51	Calcium crown
Blue	...	2·44	1·515	Fused beryl
Emerald-green	...	2·49	1·516	Fused beryl
Pale blue...	...	2·70	1·59	Calcium-iron
Colourless	...	2·87	1·54	Light flint (lead)
Yellow	...	3·627	1·633	Flint (lead)
Ruby-red...	...	3·69	1·63	Flint (lead)
'Jade'	...	3·73	—	Flint (lead)
Colourless	...	3·74	1·635	Flint (lead)
Pale blue...	...	3·84	1·642	Flint (lead)
Orange-brown	...	4·12	1·68	Flint (lead)
Red	...	4·16	1·683	Flint (lead)
Yellow	...	4·98	1·77	Flint (lead)
Refractometer	...	6·33	1·962	Extra dense flint

As can be seen, the properties of glass vary widely according to its ingredients. Of the various types which have been used to imitate gems, by far the commonest are the calcium or 'crown' glasses (consisting of silica, potash or soda, and lime) and the lead or 'flint' glasses, in which lead oxide replaces the lime in the above to greater or lesser extent. The more lead that is present, the greater the refractivity, dispersion, and density, but at the same time the hardness decreases progressively. In the borosilicate crown glasses, some of the silica is replaced by boric oxide. Borosilicate glass can be very hard (nearly 7 as against 5½ for 'crown' glass), and this is the type used in the preparation of the so-called 'mass-aqua' imitations of which the second and third specimens in the above table are examples. The lowest figures for density and refractive index are found in the 'opal' glasses, containing fluorine and certain other additions to the normal crown-glass melt. With

these, the density may be as low as 2·07, with refractive index 1·44. At the other end of the scale, 1·69 may be taken as practically the limit for the refractive index of glass imitations. The only exception to this rule encountered by the writer was the remarkable paste listed last but one in the table. This has R.I. 1·77 and S.G. 4·98. It was sent over from Burma as a specimen topaz at £2 per carat, and in its freshly cut state it looked magnificent. A few months of wear would have reduced it to a sorry state, as such heavy lead glasses are extremely soft and susceptible to tarnish. Last in the table comes the heaviest type of lead glass, used in some refractometers, and quite unsuitable for other purposes; it is included merely as a matter of interest.

So far as specific gravity and refractive index are concerned, the only glasses liable to cause confusion with actual gemstones are the calcium-iron glasses with constants near those for beryl, and those of the lead glasses having values close to those for topaz. On account of their higher dispersion (more nearly matching that of the refractometer glass) the lead glasses with refractive index over 1·60 give a sharper shadow-edge in white light on an ordinary refractometer than any gem of similar refractivity. With a spinel refractometer the reverse is true: while gems give a sharp shadow-edge, lead-glass imitations show a colour fringe which is very distinctive.

The fused **Beryl Glasses** listed in the table have the same composition as the beryl from which they are made, but they are non-crystalline and thus have lower constants. As another example of the lower constants of a glass compared with a crystal of the same composition one may cite fused quartz, which has S.G. 2·21 and R.I. 1·46 against the figures 2·65 and 1·54–1·55 for the crystalline mineral. The beryl glasses are very hard (about 7) and can be made in various colours, such as blue, by addition of cobalt, and green by addition of chromium oxide. Usually they contain numerous large bubbles.

Glass which is coloured by cobalt has a characteristic absorption spectrum containing three broad dark bands centred at about 6550 Å in the red, 5800 in the yellow, and 5350 in the green. They appear a rich red under the Chelsea colour-filter. There are other blue glasses having no distinctive absorption spectrum, which appear a dirty green under the filter. Red glasses coloured by selenium have a single broad band in the green of their ab-

sorption spectrum, not unlike that seen in red tourmaline. Pink or red glasses containing rare earths and showing a strong didymium absorption spectrum are sometimes seen.

Glass imitations are often moulded, or very badly cut, showing the ridge marks left by the mill—another indication of their nature. Where the table facet is not truly plane there may be difficulty in getting a good reading on the refractometer.

Figure 37. Bubbles and swirl marks in moldavite

Imitations made from synthetic resins or plastics will be considered in the discussion on amber in Chapter 21.

In addition to man-made glasses there are several types of glass found in nature which may be conveniently mentioned here.

Silica-glass, consisting of almost pure silica (S.G. 2·21; R.I. 1·46), was first found some years ago lying on the surface of the sands of the Libyan desert, from which it had apparently been derived. It has a pale yellowish green colour, and is slightly opalescent. The glass formed from fusion of sand in the Mexican desert as a result of the first atomic bomb retained considerable radioactivity.

Obsidian is a volcanic glass, produced by the rapid cooling of molten rock material which would have produced granite if

allowed to cool slowly. It is usually a very dark brown in colour, though iridescent, and mottled brown and black types have been found, and make rather attractive beads. The specific gravity is near 2·4 and refractive index 1·50, hardness being about 5 on Mohs' scale. Ordinary clear green bottle-glass such as may be picked up on the sea beach, or even blue artificial glass, has been fashioned and sold as 'obsidian' to the ignorant public at seaside resorts. Under the microscope obsidian shows signs of incipient crystallization not seen in artificial glass.

Moldavite is the name given to clear green or brownish green varieties of small glassy bodies known as tektites, which are found in various parts of the world. Their origin is assumed to be meteoric, but is really unknown. The properties of moldavite are practically the same as those of obsidian, but the internal characters are quite different. Moldavite contains large and numerous bubbles and swirl marks (see Figure 37), and lacks the incipient crystals which are seen in obsidian.

DOUBLETS

Doublets, as their name suggests, are composite stones made by cementing or fusing together two or more pieces of material. Such composite stones can be divided into at least three categories:

(a) True doublets, in which the crown and the base are both formed from pieces of the stone represented by the complete specimen, the idea being to unite two thin slices of material into a more important whole. Such true doublets are rarely encountered. An opal doublet in which a thin slice of precious opal is cemented to a base of less precious opal matrix can perhaps be included in this category.

(b) Composite stones in which the crown and base are both pieces of real stone, but have sandwiched between them an intermediate layer, usually of glass, which provides the desired colour. Composite stones of this type are sometimes called 'triplets', though the term doublet is sufficiently accurate for general purposes. A slice of glass between two pieces of pale emerald can produce an 'emerald' of good colour, which may easily prove deceptive if the junction between the layers is hidden by the setting. A much more common and almost equally effective counterfeit is the well-known 'soudé' emerald (soudé meaning soldered or fused) in

which two pieces of quartz, chosen for the natural 'feathers' they contain, are fused together by an intervening layer of dense green glass.

(c) Doublets in which the table facet only consists of real stone (thus defeating the hardness test) and the base is formed of glass coloured according to the particular stone represented. This is much the commonest type of doublet, and the stone invariably chosen to form the table facet is an almandine garnet, a very thin slice of which is fused to the lead glass base.
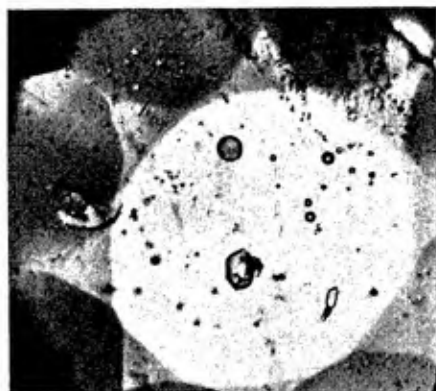
Figure 38. Photomicrograph of doublet, showing bubbles in junction plane and crystals in the overlying garnet

Detection of any of these faked specimens is usually easy where suspicion is aroused. If the stone can be obtained free from its setting, it should be held in a pair of corn-tongs below the surface of liquid contained in a white porcelain vessel or a glass-bottomed cell placed on a sheet of white paper. Viewed from the direction of the girdle in these circumstances the composite nature of the stone is very obvious when the layers are of different colours. In the rare cases where the two halves of the stone are both colourless the cement junction can be observed. Monobromonaphthalene is a good liquid to use, but water in a cup will serve quite well. If the pieces are cemented and not fused together, warming in alcohol will often cause them to fall apart.

With the ordinary garnet-topped doublet, the slice of almandine

is extremely thin, and the fine dividing line between this and the glass base can be seen by careful examination with a lens, even if the stone is in a setting. There is a distinct difference in lustre between the garnet and the glass surface which makes the junction between the two very noticeable by reflected light to the practised eye. Placed face downwards on a sheet of white paper, and viewed from above, such doublets will show a rim of red near the girdle of the stone, unless the base is also red, in which case the effect will be masked. Under the microscope, the junction between the layers is seen to be marked by a series of bubbles in this plane, when the stone is viewed through the table facet, often with crystals in the garnet visible in the same field. (See Figure 38).

Since most doublets are not composed even in part of the stone

Figure 39. *Diamond doublet, show-ing reflection effect when looking down on table facet*

imitated, a refractometer test will reveal the fraud. In the case of garnet-topped doublets the table facet will yield a refractive index reading of about 1·79, and the back facets will read about 1·63, corresponding to the lead glass used for the base of the doublet. Soudé emerald will give a quartz refractometer reading, but care must be taken not to confuse this with an emerald reading, which is only 0·02 or 0·03 higher on the scale. A new type of soudé emerald has recently appeared in which the upper and lower portions consist of synthetic white spinel, the two being cemented together with an emerald-green layer between them. These appear green under the Chelsea filter, and give the typical refractive index and tabby extinction of synthetic spinel.

Doublets with a crown composed of diamond, cemented to a

base of rock crystal or synthetic white sapphire are occasionally encountered. Though these have the adamantine surface lustre of diamond they are notably lacking in 'fire' and can be 'seen through' when viewed obliquely through the crown. There is a curious reflection of the edges of the table facet in the junction layer, which is readily noticeable when the stone is tilted. (See Figure 39.)

Granted that a true diamond doublet in which both crown and base consisted of diamond would be harder to detect, yet, once suspicion has been aroused by the 'wrong' look of the stone, and the possibility of the nature of the fraud has been realized, the detection of any doublet, however cleverly made, should not be a very difficult matter. An ingenious jadeite doublet simulating fine green jade is described in Chapter 20.

COATED STONES

A warning note on a recent process for coating the upper surface of gemstones with a film of low refractive index to improve their brilliancy and apparent depth of colour may be given here. Such a film reduces the surface reflections in similar manner to the coating or 'bloom' on lenses in cameras and binoculars, and allows more light to enter the stone. There is, of course, a reduction of surface lustre. Such treatment is a form of 'faking', and as such, should be condemned.

Coated stones can be recognized by a slight bloom or iridescence of the surface. Refractive index readings on the refractometer may be unobtainable until the coating has been removed by rubbing with rouge or similar polishing agent.

THE USE OF THE MICROSCOPE

TO THE gemmologist, the microscope is undoubtedly the most essential of all instruments. In everyday practice the jeweller is far more often concerned with distinguishing natural stones from their synthetic counterparts, or in detecting imitation stones than he is in separating natural stones of different species. And, as we have seen in the previous chapter, in detecting all manner of counterfeits the microscope is supremely important.

But its importance does not stop there; its powers of distinguishing one stone from another are also very considerable, since the nature of a stone and even its place of origin can often be deduced from a study of its inclusions as revealed by the microscope. The nature and depth of flaws can also be determined, the presence of double refraction detected and its extent approximately gauged, and refractive index also can be assessed with the aid of immersion liquids.

The study of mineral inclusions began in the nineteenth century, but until recently such work was sporadic and unco-ordinated. During the past few decades it has been coming into its own as a new and practical means of identifying gemstones and of understanding something of the conditions under which they were formed in nature. This indeed is one of the most important contributions of gemmology to the parent sciences of mineralogy and geology. The recent advances in inclusion study are chiefly due to the researches and enthusiastic advocacy of Dr Edward Gübelin of Lucerne. Many of his articles on the subject, illustrated by splendid photomicrographs, have appeared in the journals, and he has also written a book *Inclusions as a Means of Gem Identification* in which most of his work is epitomized. The subject is a vast one, however, and plenty remains to be discovered by the patient and acute observer, and many problems still await solution.

Microscopes specially designed for use by jewellers and gemmologists have been developed by Prof. Schlossmacher in Germany, Shipley in America, Gübelin in Switzerland, and by Rayner in this country. Unfortunately, most of these are either expensive

EYEPIECE

COARSE
ADJUSTMENT
CONTROL

BODYTUBE

LIMB

ROTATING
NOSEPIECE.

FINE
ADJUSTMENT
CONTROL

OBJECTIVES

SUBSTAGE
CONDENSER

STAGE

INCLINATION
JOINT

MIRROR.
FOCUSING
CONTROL FOR
CONDENSER

FOOT   WATSON
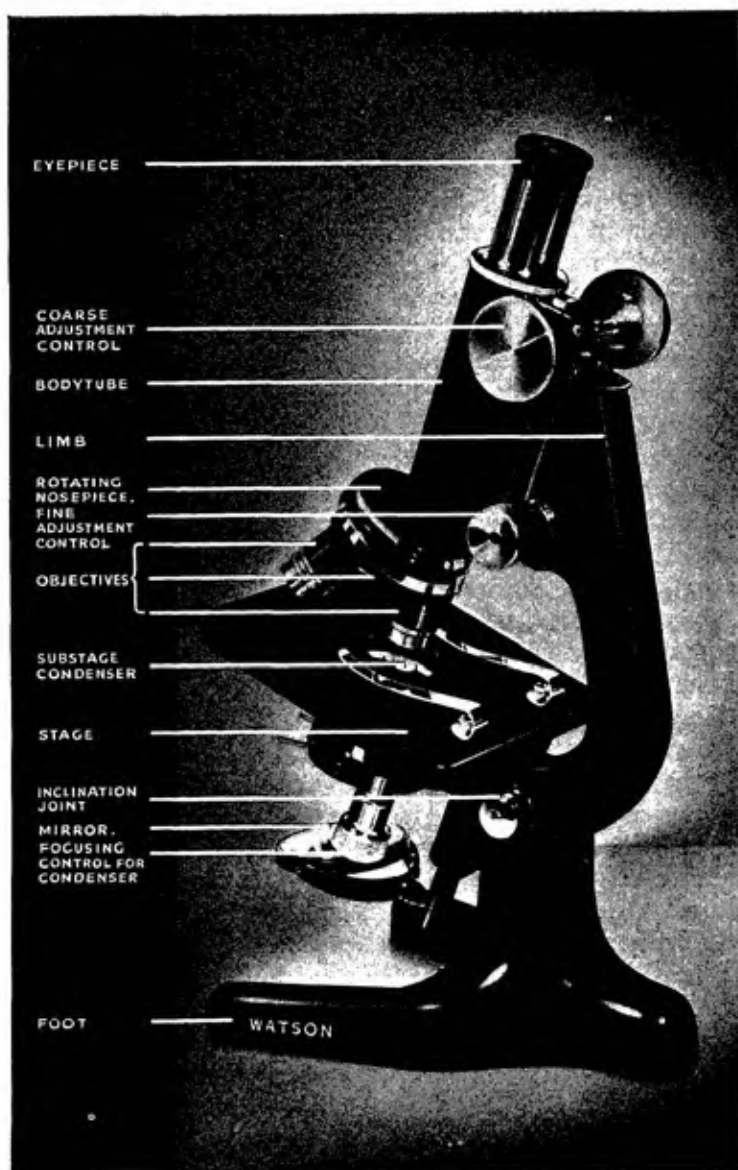
*Figure 40. The 'Kima' microscope for students and laboratories.
British-made by W. Watson & Sons Ltd.*

or not readily available; the special 'petrological' microscopes used by the mineralogist are also expensive luxuries.

Luckily, most of the essential work needed can be carried out with quite a simple form of microscope, and we shall begin by describing a typical standard instrument and the manner in which it may be used in the study of gemstones.

There are two lens systems producing the magnifying effect in a microscope, each being mounted and handled as a single piece. The lower group is known as the *objective*, and the upper as the *eyepiece* or *ocular*. The objective is screwed into the lower end of the *body tube* of the instrument, and the eyepiece is slid into the upper end of the tube. The total magnification produced depends on the power of the objective, the power of the eyepiece, and the length of the microscope tube. The microscope *stand*, as the whole instrument (without the eyepiece or objective) is called, consists of a heavy metal base or *foot* to which is hinged a heavy metal *limb* by which the microscope is carried or lifted from its case and to which is attached a platform called the *stage* with a circular aperture in the centre through which the light reflected from the adjustable *mirror* of the microscope reaches the specimen to be examined. The body tube of the microscope (which often contains an inner *draw tube*) is attached to the limb and may be raised or lowered for focusing by a rack and pinion movement operated by two milled heads turning in the vertical plane on either side of the body tube.

This focusing arrangement, which has a play of several inches, is known as the *coarse adjustment* and is all that is needed to obtain sharp focus with low or medium powers. Better-class microscopes are also fitted with a *fine adjustment* focusing arrangement for making the final delicate focusing adjustments with higher power objectives, with which the focus is extremely critical.

In addition to the simple optical system of mirror, objective, and eyepiece, it is useful for our purpose to have a *substage condenser*; that is, a condensing lens fitted beneath the microscope stage, preferably combined with an iris diaphragm in the same fitting, housed below the microscope stage. This provides a convergent beam of light which greatly assists in illuminating a faceted specimen satisfactorily when it is not immersed in a liquid. It is a great convenience if this is adjustable by means of a rack and pinion.

The magnifying power of objectives is usually indicated by their focal length; the shorter this is, the greater the magnification. Medium- or low-power objectives, notably $\frac{2}{3}$ in., 1 in. and $1\frac{1}{2}$ in. used in combination with a low-power eyepiece, will give all the magnifications needed for stones, that is, from 25 to 70 diameters.

The advantages of using fairly low powers are that (a) one can see more of the specimen in the field of the microscope at any one time; (b) the depth of the focus is greater; and (c) the working distance between the specimen and the front lens of the objective is also greater, so that one is less likely to damage the soft glass of the lens by contact with the hard edges or corners of the stone. Generally speaking, too, the definition is clearer with the lower powers and observation is much easier for the beginner.

Having thus very briefly detailed the main features of a standard microscope we can proceed to describe how it can best be used in examining the internal features of faceted stones. Incidentally, the microscope can of course also be used to examine the *external* surface of a stone if necessary; for instance, the precise nature of a chip or a flaw where it reaches the surface, the quality of the polish, and so on. Examination of a stone in its setting is sometimes necessary and can usually be managed if the setting is an open one, but it is undoubtedly more difficult than with an unmounted gem, and the beginner will be well advised to practise first with the latter, as described in detail below.

To accustom himself to focusing the microscope the beginner should at first start by examining simple objects such as scraps of blotting-paper, cloth, leaves, etc. These will lie flat on a plain glass microscope slide placed on the stage of the microscope and can easily be focused, the specimen being illuminated by an adjustable microscope lamp or reading lamp placed near to one side and rather above the level of the stage.

It should be noted that in examining stones it is necessary to use the microscope with the body tube in the vertical position, that is, with the stage horizontal, to prevent the stone, which is held in position only by gravity, from rolling off the stage. When observing an object mounted properly as a microscope slide, this is usually clipped into position on the stage, and the limb can then be tilted back towards the worker into a position which is more comfortable for prolonged scrutiny. The 'working distance' of any objective will be found to be rather less than the focal

distance length by which the objective is known. A much greater 'working distance' is available when using a Greenough-type binocular microscope, described later.

Having accustomed himself to the 'feel' of the microscope, the operator can now proceed to examine a stone. To make things easy to start with, take a plain glass microscope slide and a small piece of plasticine. Roll a small ball of plasticine about the size of a pea (whether sweet pea or green pea must depend upon the size of the stone) and press this gently on to the slide near the centre. Then, having wiped the stone scrupulously clean, place it on the slide with the table facet uppermost and horizontal, the culet resting on the slide, and the stone supported by the plasticine near the girdle. Now place the slide on the stage of the microscope with the stone directly under the objective, which should then be racked down by means of the coarse adjustment until nearly touching the surface of the stone, while watching from the side to ensure that it is not allowed actually to touch. The operation of focusing the internal parts of the stone as seen through the table facet can now proceed with safety, since this will be accomplished by *raising* the focus, thus avoiding the very real risk of overshooting the mark in attempting to focus *downwards*.

In focusing upwards, as suggested, one should soon see the culet and the edges of the adjoining facets come into view; then, continuing to raise the focus slowly, the image of these should disappear, and before very long the surface of the table facet should be faintly visible by reason of fine particles of dust settled upon it and sometimes slight imperfections of the surface such as polish marks, etc. If in the middle of the stone there are any flaws, inclusions, or bubbles, these will appear in sharp focus at some point between the correct focus for the culet and the table. If one is uncertain whether the table facet level has been reached (and this admittedly is not always easy to see) one can check on this by pushing the slide along a little, when the edge between the table facet and other crown facets should be clearly visible. The observer will find that moving the slide to the left will cause an apparent movement to the right as seen through the microscope.

By adjusting the distance of the condenser below the stage and tilting the mirror at the correct angle the best position can soon be found for obtaining optimum illumination of the interior of

the stone. Stones can also be examined, of course, table facet down on slide; only one is then apt to be confused by the reflections and refractions caused by the many small facets. When one is completely at home with the microscope it will be found a simple matter merely to hold the stone table facet upward between thumb and forefinger of the left hand, resting the hand on the microscope stage to assist one in steadying the stone. One can then focus the microscope down on to the stone safely, since the fingers will act as buffers to prevent the objective coming into contact with the specimen. Stones too small for this treatment can be held in tongs.

In the methods suggested above, it is essential for good results to have a substage condenser. Even so, the examination of the stone will be probably not quite complete, but will be chiefly confined to that part of the stone directly beneath the table facet. Small inclusions and other features near the girdle may therefore be missed. To make a more thorough examination of a 'difficult' (i.e. very clean) stone it will be advisable to immerse the stone in a glass or glass-bottomed cell containing a liquid of refractive index fairly near to that of the stone examined. Only just enough liquid to cover the stone completely should be added and the stone, the cell, and liquid should be clean so as to avoid particles floating at the surface of the liquid or adhering to the surface of the stone which will make observations more difficult. This can be done by filtering through folded filter paper in a glass funnel. A good immersion liquid to use is monobromonaphthalene, a liquid compound of bromine and the naphthalene which is so well known in the form of 'moth-balls'—the liquid itself has something of the 'moth-balls' smell. Methylene iodide is also often used, and has a refractive index (1·745) more nearly approaching the 1·76 of corundum than has monobromonaphthalene (1·66); but this close matching of the refractive index between stone and liquid makes the edges and facets of the former become practically invisible and this renders it difficult to 'find one's way about' in the stone. With monobromonaphthalene, refraction between the liquid and the stone is sufficiently small to allow the specimen to be easily examined throughout, but enough can be seen of the edges of the facets to enable the observer to know what part of the stone he is examining. Failing these liquids, bromoform or bromobenzene will serve. The best cells to use are those in which a ring of glass is

fused or firmly cemented to a plain glass base. These are obtainable from R. & J. Beck, and from Rayner, London.

When examining a stone in liquid it is normally convenient to place it so that it rests on its table facet. Care must be taken not to confuse air bubbles clinging to the surface with internal bubbles which may be found in synthetic stones. External bubbles usually are larger and look more luscious than those found in synthetics, and can be removed by wiping the stone, while internal bubbles, of course, will 'stay put'.

A few words as to the choice of a microscope may be helpful. Unless one is an experienced microscopist it is better to purchase an instrument from a reputable firm, whether it be new or second-hand, as in this case the instruments so sold will be guaranteed to be optically sound, For occasional use a simple monocular stand of the type already described is quite adequate, but where stones are to be examined for prolonged periods some form of binocular instrument is preferable as it involves far less strain on the eyes.

The best for the purpose are undoubtedly stands of the 'Greenough' type with paired objectives. These have a long working distance, considerable depth of focus, and give erect vision—that is the orientation of the objects seen under the microscope is not reversed. This general type of instrument is made by many optical firms, some with and some without a stage, some with the usual mirror, others with built-in lighting. A substage condenser can be fitted as an extra, and is almost essential for the gemmologist; this should be adjustable, in order to allow for flexibility in the lighting of the stone. The fullest illumination is obtained when the condenser is raised, but fine details such as curved striae in a synthetic ruby show up much more clearly when the condenser is lowered. For prolonged work with the microscope, inclined eye-pieces are a great advantage. A 'Greenough' microscope fitted with such eyepieces and with an adjustable substage condenser and diaphragm is made by R. & J. Beck, London, and is illustrated in Figure 41.

It is a wise plan before purchasing either a new or secondhand microscope to try it out on a few stones containing inclusions, as often an instrument which will give excellent results with thin sections mounted on slides may prove unsuitable for the three-dimensional examination of gemstones. Above all it must be remembered that high-power objectives such as $\frac{1}{8}$ in. are useless in

the examination of gems; 1 in. or 1½ in. are the most generally useful, giving magnifications of about 20 to 30 diameters, according to the length of the body tube and the power of the eyepieces used. A double or triple nosepiece, enabling objectives of different power to be swung into position quickly, is a useful adjunct to the standard microscope.
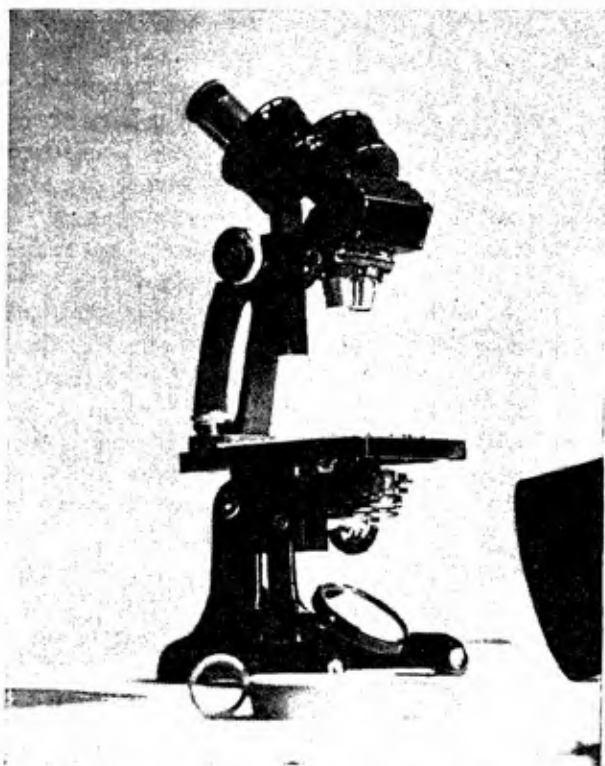
Figure 41. 'Greenough'-type binocular microscope with inclined eyepieces and substage condenser. Made by R. & J. Beck, London

So far the question of illumination when using the microscope has been barely touched upon. Since daylight is such an uncertain and uncontrollable factor, it is usually better to employ artificial light. Many forms of special microscope lamps are on the market, but an adjustable desk lamp will often serve the purpose very well, provided that this has an opaque or nearly opaque shade to cut

out the glare produced when bright light, other than that from the microscope mirror, reaches the observer's eyes. An opal bulb of 40 or 60 watts is usually most suitable. 'Dark-ground' illumination has many advantages, and is extensively used for the study of inclusions (particularly those in diamond) in the U.S.A. and in Switzerland. The most usual arrangement is to have a small low-voltage lamp 'built-in' to a substage housing consisting essentially of a silvered bowl-shaped reflector. Direct light is prevented from entering the stone by a suitable stop, while oblique rays enter the specimen from all sides by reflection from the silvered reflector. Immersion in liquid is not necessary: the stone can be gripped in spring tongs attached to a pivot on the stage. Any feathers, flaws, or inclusions are clearly visible, being brightly lit against a dark background. This form of illumination is particularly suitable for diamond, through which it is difficult to transmit light in the ordinary way because of its high refractive index.

Dark-ground illumination has been catered for in a new form of microscope specially designed for gemmologists which has recently been marketed by Rayner. This incorporates many ingenious features. The stand is a monocular one, with inclined eyepiece. Focusing is accomplished by raising or lowering the stage and substage, which form a single unit with built-in lighting and a polarizer and occluder (for dark-ground illumination) which can be swung-in when required. A glass cell is supplied which hangs by its rim below the level of the stage, and the stone is held therein by an ingenious holder. The specimen can be observed either dry or immersed in liquid, and by transmitted light or dark-ground illumination. Any of the three parfocal objectives can be brought into use by turning a knob, giving magnifications of 10, 25, and 60. In place of the eyepiece, a specially designed prism spectroscope can be fitted into position for an examination of the absorption spectrum of a gem.

In conjunction with J. Asscher Jun. (of the famous firm of diamond cutters in Amsterdam) a modified form of Rayner microscope is available with which it is possible to measure the depth of a flaw or inclusion below the surface of diamond or other gem-stone—information of great value where re-cutting is contemplated.

It is often necessary for the gemmologist to examine stones in their settings, and this can be an awkward business. A stone-set

brooch can usually be place on the stage and thus examined fairly easily. When examining stones in a ring it is usually necessary to look through the back of the stones so that the particular stone under examination rests more or less with its table facet on a glass

Figure 42.   Rayner gemmological microscope

plate on the stage, only tilted sideways sufficiently to prevent the shank of the ring obscuring the view of the stone.

Ring-stones are usually dusty at the back of the setting, and it is well worth while to clean them thoroughly with benzene or methylated spirit and a small camel-hair brush before attempting to examine them.

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One can, of course, hold a ring with the stone uppermost so as to look through the table facet, but it is difficult in this position to obtain sufficient illumination. Most difficult of all to examine are backed stones, which can only be examined by overhead light. Even here, however, often enough detail can be seen within the stones to enable one to determine whether they are natural or synthetic.

If it is required to immerse set stones for their better examination it is advisable to use a glass dish of ample size, say 3 in. to 4 in. diameter, in which the piece of jewellery can be placed and completely immersed. Some inexpensive and volatile liquid such as toluene should be used (in spite of its relatively low refractive index) to avoid waste of the more expensive liquids and also to avoid having afterwards to clean the jewellery to remove the oily and smelly remnants of the immersion medium.

In Chapter 3 it was explained how double refraction in gemstones (an important distinguishing factor) could be detected by observing with a lens the apparent doubling of the edges of the back facets when viewed with a lens through the front of the stone.

In stones which have large double refraction such as rutile (0·287), sphene (0·12), zircon (0·059), peridot (0·036) and even in tourmaline (0·018) this should with practice be easily observed with a strong pocket lens even in small stones, but with species in which the double refraction is small, such as quartz (0·009), topaz (0·009), corundum (0·008), chrysoberyl (0·009), and beryl (0·006), the effect cannot be detected with a lens unless the specimen is large.

The microscope, however, enables one to extend this direct observation of double refraction even to those gems in which the effect is small, and of course, makes it far more noticeable with those in which the double refraction is strong. In the 'petrological' type of microscope there are available two 'Nicol prisms' (or polarizers made of Polaroid which fulfil the same purpose) which enable one to carry out the most sensitive of all tests for double refraction. This particular test between 'crossed Nicols', as it is called, was briefly explained in Chapter 3. It was there mentioned, also, that a number of isotropic (i.e. singly refractive) substances, including glass, may show a certain amount of double refraction when under a condition of strain.

Such traces of anomalous double refraction, however, will

never be large enough to cause the 'doubling' effect under the microscope, so that when this is seen, one may be sure that the stone is really doubly refractive and thus cannot be a paste or a mineral crystallizing in the cubic system. Such evidence is often of great practical importance and can be carried out at the same time as one is observing the internal inclusions of a stone. When, for instance, one is examining a reputed sapphire, which may be either a synthetic sapphire, a blue paste, or (less likely) a synthetic spinel, if the edges of the bubbles or of the back facets as viewed through the table are seen to be doubled then this establishes without further test that the stone is a synthetic sapphire, since glass or spinel would show no such evidence of double refraction.

As with all the other instruments mentioned in this book, good results can only be obtained by practice, but with a little perseverance any ordinarily intelligent person can handle a microscope with profit and pleasure.

PHOTOMICROGRAPHY

The keen student will sometimes wish to make a permanent record of some interesting feature or inclusion. Provided a good microscope is available, and the experimenter is sufficiently patient to arrange his lighting to the best advantage, it is not a very difficult matter to procure a reasonably good photomicrograph.

The simplest technique of all, involving no camera, is to remove the eyepiece and place a piece of finely ground glass on top of the body tube of the microscope, and, in a darkened room, to focus the microscope until the desired features can be seen sharply defined on the ground-glass surface (this surface, or course, should be the one in contact with the body tube). The microscope light should then be switched off, and, in darkness, a piece of slow 'line' film be placed, emulsion downward, in place of the ground glass. This can be covered by a small square of cardboard or other light, opaque object. The lamp is then switched on for a sufficient length of time to make the required exposure, which may mean anything from about half a second to thirty seconds or so, according to the subject. When developed, the film should show a good sharp image, which can of course be enlarged to taste at a later time. This method does not lend itself to masterpieces of photomicrography, but is cheap and simple.

If one of the forms of 35 mm camera is available, it is not difficult to take photomicrographs either in black and white or in colour. In this case the eyepiece is not removed, but the desired features are carefully focused using the microscope in the ordinary manner. The camera is then focused for infinity and the aperture set for a fairly wide stop (say f/4). The camera can then usually be balanced with its lens resting on the eyepiece of the microscope, and an exposure be made either by fixing the shutter open and operating the microscope lamp for the required time, or by setting the shutter to 'bulb' and using a cable release. If the lighting is sufficiently strong to enable exposures of under a second to be made, the marked shutter speeds can be utilized with advantage, and the 'self-timer' clockwork device resorted to. This obviates risk of shifting the camera while operating the shutter. For steadiness and safety it may well be preferred to rig up some form of stand for the camera rather than simply to let it rest as suggested above.

The chief difficulty, apart from arranging the field so that all the required features are correctly lit and in focus, is in gauging the exposure time, especially where colour photographs are attempted. This, of course, is very largely a matter of experience, but some form of 'extinction meter' may be found helpful. The ordinary photoelectric exposure meter will be found not sufficiently sensitive to function properly under these conditions.

If some special form of microcamera is desired, the least expensive type is simply a conical attachment with one end made to fit over the eyepiece, while the other (larger) end is fitted with a plate-holder. The image is focused on a ground-glass screen before putting a plate into the holder and making the exposure. This form of camera takes a larger initial picture, and subsequent enlargement may not be necessary, though the cost of the plates is, of course, much greater than for small pieces of film.

THE USE OF THE SPECTROSCOPE

THE spectroscope is the third leg of the tripod of instruments on which modern determinative gemmology rests secure. The other two instruments forming the 'tripod' are, of course, the refractometer and the microscope.

We have seen how the refractometer enables us to determine the species of most faceted gemstones, while the microscope tells us of their origin. But the refractometer cannot be applied to rough stones, and cannot give readings with stones of high refractive index; and under the microscope not every stone displays revealing features. The spectroscope, it is true, also has its limitations, but often it can fill the gaps left by the other two standard instruments, and for a number of gems it provides the most rapid positive test available. It can be applied as easily to rough stones as to polished gems, and as easily to stones of high index as to those within the range of the refractometer. In many cases the spectroscope can determine the natural or synthetic origin of a gem, and detect cases of artificial coloration.

All this it does merely by analysing the light transmitted by a gem or reflected from its surface. We have already seen in Chapter 4 that white light consists of a mixture of all the colours of the rainbow: red, orange, yellow, green, blue, and violet. Of these, red has the longest wavelength and violet the shortest, the range of visible light being approximately from 7000 to 4000 Ångström units. Beyond the red end of the spectrum are invisible so-called infra-red rays which merge into the heat waves of still longer wavelength. Beyond the violet end of the spectrum are the invisible ultra-violet rays, which occupy the range 4000 to 2000 Å. X-rays, which have the same essential nature as light rays, have wavelengths of the order of 1 Å only.

The manner in which the spectroscope analyses light into its component wavelengths is in principle very simple: it depends upon the different degree of refraction which rays of each colour (wavelength) undergo when they are made to pass through a prism made of glass or other transparent substance. Thus a narrow parallel beam of white light, after passing through a prism,

is spread out into a ribbon of rainbow colours—the visible spectrum. A spectrum can also be formed by passing light through a grating of lines spaced very closely at regular intervals. Such a grating is known as a 'diffraction grating' and is used in many spectroscopes. Both prism and grating spectroscopes have certain advantages and disadvantages. Prism spectroscopes produce a brighter spectrum, but the 'spread' of colours becomes greater and greater towards the violet end, in accordance with the increasing dispersion of the glass or other medium used for the prisms. With a diffraction grating there is an even spread of colours throughout the whole spectrum range, but since a series of spectra are produced on either side of the incident ray, far less light reaches the eye in the one spectrum which is observed. Since the brightness of the spectrum seen is of prime importance, the author recommends the use of a small prism spectroscope for 'spotting' purposes, and for the rapid diagnosis of gemstones by means of their absorption spectra. Such a spectroscope consists essentially of a metal tube, at one end of which is fitted an adjustable slit through which the light to be examined is admitted. Beyond this is a lens to render rays from the slit parallel: then a series of three or five glass prisms which are in contact and with their refracting edges in opposing directions. Glass of a different degree of dispersion is also used in alternate prisms of the group, with the result that rays in the middle of the spectrum emerge from the eyepiece very little deviated. This constitutes a 'direct vision' spectroscope. Ideally, the total dispersion should be about 10°, which just enables the observer to see the whole of the visible spectrum. The lines in different parts of the spectrum can be brought sharply into focus by means of the draw-tube of the instrument. For the red end of the spectrum it will be found necessary to pull out the draw-tube about $\frac{1}{4}$ in. For blue and violet rays the focus is sharp when the draw-tube is pushed right home.

If the slit of a small pocket spectroscope be directed towards an electric light bulb a rectangular ribbon of the spectrum colours will be seen. When turned towards the sun or a bright sky the same continuous band of colours can be observed, but if the slit width is narrow enough, and the draw-tube of the instrument is correctly adjusted for sharp focus a series of fine dark lines will be discerned crossing the bright ribbon of colour. The lines referred to are at right-angles to the length of the spectrum: any dark

lines or streaks parallel to the *length* of the spectrum are due to dirt on the slit, and can usually be cleared by opening the slit very slightly. The dark lines crossing the spectrum are known as the Fraunhofer lines of the solar spectrum after the German physicist who first described and mapped them.

Fraunhofer called the more prominent of the lines A, B, C, etc., starting from the deep red end (see glossary). We now know that these are *absorption* lines corresponding exactly in position (that is, in wavelength) with the bright lines emitted by the glowing vapour of metallic elements. Two lines in the yellow, for instance, so close together that they appear as one line in a small spectroscope, correspond exactly with the yellow lines emitted by glowing sodium vapour. These lines can be seen in great strength when a yellow sodium street lamp is looked at through a spectroscope, and in fact appear in almost any flame, so ubiquitous is the element sodium and so sensitive is this test for its presence.

Putting the matter as briefly as possible, this *absorption spectrum* of the sun is produced because certain wavelengths of the bright continuous spectrum emitted by its glowing solid core are absorbed by metallic atoms in the cooler gaseous atmosphere which surrounds the star. Each kind of atom in the gaseous state has the power to absorb those same wavelengths of light which it emits when heated. But in solids the absorptive power of the atoms it much more restricted than in gases, and any absorption bands are much broader, more vague in outline and variable in position than the Fraunhofer lines described above. However, the fact that the absorption bands vary in position according to the mineral in which the colouring metal occurs is in itself a distinct advantage, as it enables us in many cases to identify the mineral.

There is a small group of metals which, when present in a solution or glass or mineral, tend to absorb certain wavelengths from white light and thus exert a colouring action on the substances which contain them. The most important so far as gemstones is concerned is chromium, which produces the splendid reds of ruby, spinel, and pyrope, and the rich and brilliant greens of emerald and jade. Iron, nature's most common colouring agent, gives rise to less brilliant greens as well as red and yellow and occasionally blue. Green sapphire, peridot, almandine and blue spinel are examples of these. The influence of copper is seen in turquoise, and in the ornamental stones malachite and azurite. Manganese

provides a peculiar rosy pink or orange in the rare spessartite garnet and the translucent rhodochrosite and rhodonite. Nickel earns credit for the green of true chrysoprase. The well known blue of cobalt is not found in natural minerals, but is common in blue glass and in the blue synthetic spinels which are so prevalent to-day.

This forms a convenient point to return to the subject in hand, which is to explain how a spectroscope enables one to analyse the colour of a gemstone and hence, in many cases, to determine the nature of the stone. A piece of blue cobalt glass is not difficult to obtain, and provides perhaps the easiest demonstration of what we mean by absorption bands and an absorption spectrum. If the spectroscope is directed to a bright continuous source of light, such as an incandescent bulb, or the sun, and the cobalt glass is then placed in front of the slit, instead of the complete series of spectrum colours formerly visible the observer sees virtually only two colours —a patch of blue, as one might expect, and a patch of deep red, which may seem somewhat surprising in a blue material. The remainder of the spectrum is blotted out by three broad dark bands centred in the orange, yellow, and green. This, then, is the typical absorption spectrum of cobalt, and is seen, as indicated above, not only in cobalt glass but also in synthetic blue spinel, though the position of the bands differs slightly in the two cases.

When the specimen to be examined is not a flat sheet of glass but a faceted and often mounted gemstone, it will be realized that it is not such an easy matter to pass light through the stone on to the spectroscope slit. Before describing the more important gem spectra, therefore, it will be wise to give some advice on the methods of going to work which have proved most satisfactory, and to consider what types of spectroscope and what sources of light are most suitable.

The best small spectroscope of which the author has personal experience is the prism spectroscope No. 2458, made by R. & J. Beck, London, and a growing number of gemmologists are using this model with good results. A very similar instrument is now made by Rayner.

For those who wish to take the study of absorption spectra seriously and make their own measurements of wavelengths, there is a Beck 'Wavelength' spectroscope in which the fine cross-hairs in the eyepiece can be adjusted to any absorption band by rotating

a drum which is calibrated directly in wavelengths. The accuracy is about ± 5 Å.

A more accurate but more expensive instrument by the same makers is the Hartridge Reversion Spectroscope, in which bands seen in reversed images of the spectrum are made to coincide by turning a calibrated drum. There are also prism spectroscopes in which the image of a wavelength scale can be seen above the spectrum. In the latter there is some difficulty in securing correct adjustment of the scale, in avoiding troubles due to parallax, and in illuminating the accessory tube containing the scale just sufficiently to enable it to be visible without being so bright as to mask or distract the eye from the sometimes very faint bands in the spectrum that one wishes to measure.

Figure 43. Prism spectroscope No. 2458 made by R. & J. Beck, London

A spectroscope designed specially for use with gemstones has been designed by Dr E. Gübelin. This is a table instrument with built-in lighting and illuminated scale, the brightness of which can be controlled at will. The instrument is fitted with an adjustable holder for gripping the stone, the slit is adjustable, and there are other refinements to make for easy observation of gem spectra.

However, it has always been the author's contention that wavelength measurements of absorption bands are very seldom necessary for diagnostic purposes. After a little practice the nature and grouping of the absorption bands which characterize the main gem species are quite sufficiently distinctive to enable them to be recognized with certainty simply by inspection with a small prism spectroscope. After all, our ability to recognize a friend when we meet him in the street is not dependent upon our knowing the exact length of his nose or the distance between his eyes. Spectra which cannot be recognized at sight even by an experienced

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observer are of little value for purposes of identification, even when the wavelengths of the bands are measured.

The source of light should be as powerful as possible. Quite a lot can be done with a 60- or 100-watt frosted bulb in a microscope lamp or a desk lamp, but the beam from a low-voltage 'intensity' lamp is better and the author prefers still more to use a 500-watt projection lamp housed in an asbestos-lined box to avoid any glare reaching the eyes except through the specimen.

The most convenient means of concentrating light on to the specimen and ensuring that the transmitted light adequately and evenly covers the slit of the spectroscope is to bring a microscope into service. A simple microscope with a substage condenser is ideal for the purpose. The stone to be examined is placed on a glass slide on the stage of the microscope and the eyepiece removed. A low-power objective, 1 in. or 1½ in., should be used. Looking down the microscope tube, the stone can now be brought into focus, only slightly enlarged. The mirror and condenser should now be adjusted and the position of the stone so arranged as to give the greatest possible amount of transmitted light in the centre of the field. The focus of the microscope should then be raised somewhat, so that the field of view is filled with a uniform 'out-of-focus' glare of transmitted light. The spectroscope can next be lightly rested on the body tube in the position normally occupied by the eyepiece and, if the adjustments have been properly made, a spectrum free from horizontal streaks should be seen, evenly illuminated save for such vertical absorption bands as the stone may be causing. Still more light can be obtained by concentrating the rays from the lamp on to the microscope mirror by means of an adjustable 'bull's eye' condenser of ample dimensions. To avoid being dazzled by the glare while adjusting the specimen to best advantage it is wise either to view it through a dark filter such as the Chelsea filter, or to rest a piece of frosted glass on top of the body tube of the microscope, on which an image of the illuminated stone can be seen.

Light from a projection lamp contains a large proportion of heat rays, and, when concentrated by lenses as described, may heat the specimen unduly. Though normally this does no harm, it may be wiser when employing so powerful a lamp to filter the rays through a flask of water placed in front of the lamp. Suitably arranged, the flask of water can itself serve as a condensing lens,

and cuts out the unwanted heat rays very effectively, while passing almost all the visible light. A 600 or 750 c.c. flat-bottomed flask is ideal for the purpose. In addition to one of these filled with pure water it is well worth while to have handy a similar one filled with a concentrated solution of copper sulphate. This yields a fine blue liquid of the kind which used to be seen in large pear-shaped glass containers in chemists' shop windows. If this is made with tap water it will be necessary to filter carefully to ensure a completely clear solution. By using the copper sulphate flask as a condenser and filter it will be found that every vestige of red and orange light has been absorbed from the spectrum. This enables one to see fluorescence lines in the red (such as those emitted by ruby or red spinel, to be described later) very clearly against a dark background. It also enables one to view more clearly absorption bands in the blue and violet part of the spectrum. Naturally, one must only use the blue flask for such special purposes, since for observation of the complete absorption spectrum of any gemstone a white light source is essential.

Some workers prefer to dispense with the microscope and to concentrate the rays from their light source on to the specimen by means of a bull's-eye condenser. A water flask serves here also very well, and is considerably cheaper. The specimen is placed table facet down on a strip of black velvet and the light reflected from the interior of the specimen is examined through the spectroscope with the slit a few inches from the stone. Weak absorption bands in pale-coloured specimens appear more strongly by this method, and the bright fluorescence lines seen in ruby and spinel also show to good advantage. It is not so good as the transmitted light method for deep-coloured stones or for bands in the blue and violet. A stand for the Beck prism spectroscope has been designed by Mr R. K. Mitchell, which makes observation by reflected light a simple matter. This can be obtained from the Gemmological Association. Both methods of using the spectroscope are illustrated in Figures 44 and 45.

It is a good habit always to observe the spectrum from the same viewpoint—a simple matter of turning the spectroscope to the desired position. The author always prefers to view the spectrum as a horizontal rectangle with the red at the left-hand end and the violet at the right-hand end.

At first the slit should be fairly widely open, say about 1/4 mm

(1/100 in.); it can then be closed while the spectrum is being observed until the point where horizontal streaks (due to dust on the jaws of the slit) begin to make their appearance. The spectrum can then be focused sharply by raising or lowering the draw-tube of the instrument.

The position for sharp focus is readily found by looking through
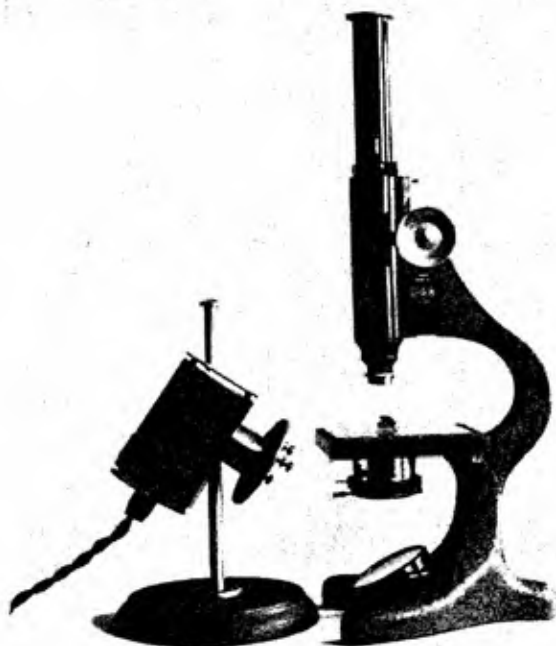
Figure 44. Arrangement for viewing absorption spectrum of gemstone, using Beck 'No. 10 London' microscope with condenser, prism spectroscope, and low-voltage 'intensity' lamp

the spectroscope at the sky, as already described. When the instrument is correctly adjusted the Fraunhofer lines should appear very clear and sharply defined. It will be found that for sharp focus in the red part of the spectrum the draw-tube has to be pulled out a quarter of an inch or so, while for sharp focus at the violet end it may need to be pushed right home. Adjustment of slit-width and focus are matters of great importance if successful results are to be obtained. Any persistent *heavy* horizontal streaks betoken dirt on the slit, in which case the jaws of the slit should be opened and

carefully cleaned by rubbing gently with an orange stick or sharpened match-stick.

Easy spectra with which to practise are those seen in brown or greenish Ceylon zircons and in almandine garnet. These happen to be 'classic' examples, since it was in these gemstones that Church, in 1866, first observed absorption bands. Synthetic ruby also shows a well-defined spectrum for practice. Details of these spectra will be found below in their appropriate places.
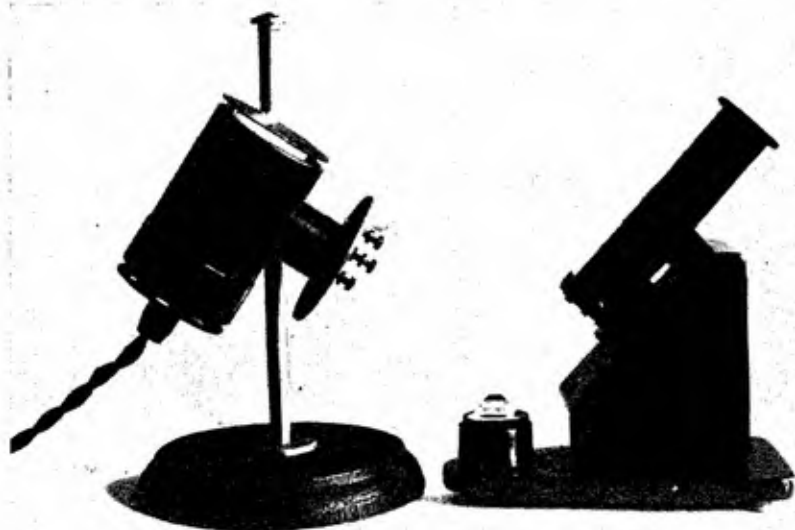
Figure 45. Arrangement for viewing absorption spectrum of gemstone by reflected light, using Mitchell spectroscope stand and Beck No. 2458 prism spectroscope

To decide in which order the absorption spectra of individual gemstones should be described is by no means an easy matter. From a scientific and systematic viewpoint it is undoubtedly best to group together those spectra which can be attributed to chromium, those which are due to iron, to manganese, and so on; and this procedure was followed in previous editions of this book. However, this method presupposes a considerable degree of knowledge on the part of the reader, and is now abandoned in favour of an arrangement based on colour.

For practical purposes this has much to commend it. After all, absorption is definitely linked with colour, and the absorption

bands seen in ruby, for instance, are quite different from those found in sapphire, though both belong to the same mineral species. Moreover, the whole descriptive portion of the book is arranged on a colour basis, in recognition of the fact that colour is the most obvious characteristic of gemstones, whether to the expert or to the tyro. All the characteristic spectra to be seen under each colour heading will therefore be found below, beginning with colourless stones and carrying through in the spectrum order red, orange, yellow, green, and blue. This naturally leads to a good deal of repetition in the case of a stone such as zircon. But this is no bad thing, since the spectrum shown by a white zircon is not to be described in quite the same terms as, shall we say, the spectrum of green zircon.
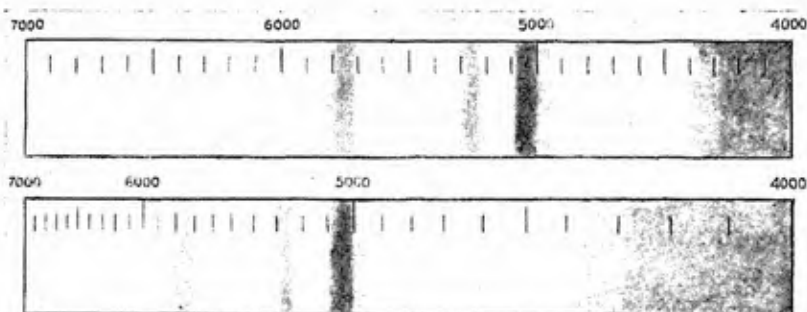
Figure 46. Distribution of absorption bands in almandine garnet as seen through (a) a grating and (b) a prism spectroscope (compare Figure 47 (5))

Another departure from previous editions is that wavelength figures are included in the text, instead of being confined to the tables. These figures may not mean anything to the beginner, but before long those who use the spectroscope come to know where to look for a line of wavelength 5200 Å as compared with another line of wavelength 5600 Å (though both must be described as 'green'), even though no wavelength apparatus be used.

SPECTRA OF THE ELEMENTS

Completely colourless stones should, of course, show no absorption bands. But the presence of narrow bands has very little influence on colour, especially where, as in the case of zircon, there are

several narrow bands evenly distributed across the spectrum. Stones which are nearly colourless are also included in this first group. Before describing individual spectra, a general account of the types of spectrum which we have learned to associate with the metallic ions which are known to give rise to colour in minerals may be given. The metals involved all belong to a group known as 'transition elements' and occupy consecutive places in the periodic classification of the elements, based on their atomic number. Beginning with titanium, atomic number 22, they continue in order, vanadium, chromium, manganese, iron, cobalt, nickel, and copper. Uranium in certain cases and some of the 'rare earth' elements may give rise to absorption bands, but have little influence on colour. In the unique case of diamond, colour is almost certainly due to defects in the crystal structure of the stone.

Minerals can be classified into the idiochromatic ('self-coloured') type which owes its colour to an element which is an essential part of its composition—e.g. the iron in almandine garnet or peridot, the copper in malachite—and the allochromatic type, in which the colouring element is present in quite small quantity as an 'accidental' impurity. The majority of gem minerals are allochromatic: that is, the mineral itself has no distinctive colour, and is in fact colourless when pure, but exhibits a range of coloured varieties according to the presence of traces of different colouring elements. Quartz, beryl, corundum, tourmaline, topaz, spinel, zircon, and many others are in this category.

Returning now to the type of spectrum associated with some of the main transition elements, we will deal with chromium first, on account of its great importance as a colouring agent. To chromium (or chromium oxide) may be ascribed the finest reds and the finest greens seen in the mineral kingdom. The red of ruby and spinel, the green of emerald, jadeite, and demantoid garnet, are all due to chromium, while in the alexandrite variety of chrysoberyl chromium produces a half-way colour which appears green in daylight and red by artificial light. Whether in red stones or in green the absorption bands due to chromium show the same general characteristics and are very distinctive. There are narrow lines in the red end of the spectrum, the strongest of which form a doublet (two lines very close together) in the deep red, accompanied by two or more lines on the orange side of this; there is a broad absorption band in the centre of the spectrum,

that is in the yellow or green. The position, width, and intensity of this band largely determines the hue of the stone. There is strong absorption in the violet, and often narrow lines in the blue.

Chromium usually enters a gemstone by replacing to a small degree the aluminium which is an essential part of its composition. Examples of this are ruby, emerald, and alexandrite. In certain cases, however, magnesium may be the element replaced—e.g. in enstatite. Colours produced by chromium are rich and clear because the absorption bands and lines are clear-cut and well-defined, the unabsorbed colours being left at full strength. Colours due to iron, though often quite attractive, are not so brilliant, because, in addition to absorption in the main bands, there is some general absorption in almost all regions of the spectrum. To use a rough analogy, chromium bands are like cities within walls, having no suburbs, the countryside in-between being left pure and undefiled, whereas iron bands are like towns spreading out into suburbs, with scattered houses spoiling the country between the main urban centres.

There are two categories of iron spectra: those due to ferrous (divalent) iron, and those due to ferric (trivalent) iron. As with chromium, the colours produced are mainly reds and greens, but the inky blue of blue spinel is also due to iron. The bands are seldom very sharp and are mainly in the green and blue parts of the spectrum.

Minerals coloured by manganese are typically rhododendron pink or orange in hue. There are bands in the blue, but the strongest bands (and these are often very intense) are found in the violet, and may extend beyond the visible spectrum into the ultra-violet region.

Cobalt minerals in nature are pink in colour, but none of these are used as gems. The familiar cobalt blue is found in cobalt glass and in blue synthetic spinel, both of which may be used to imitate sapphire. The absorption spectra of these cobalt blues are very distinctive, with their three strong, broad bands in the yellow, green, and blue-green.

The other transition elements do not give rise to distinct absorption bands, with the exception of copper in turquoise, which causes two narrow absorption bands in the violet, only one of which is usually visible.

Bands due to uranium are found only in zircon, most varieties

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of which exhibit a remarkable series of twelve or more narrow lines or bands extending throughout the entire spectrum. Because of their narrowness and regular distribution these have very little influence on the colour of the gem. Finally may be mentioned the narrow lines produced by the presence of the two rare earth elements neodymium and praseodymium, usually known by the collective name 'didymium' since they are virtually inseparable. Traces of didymium are often present in calcium minerals, because in chemical behaviour these rare earths are very similar to calcium. The strongest series of didymium lines forms a group in the yellow part of the spectrum, while there is another group in the green. The lines differ very little in position in the different minerals in which they occur. This, and their extreme narrowness may be accounted for by the fact that the electrons involved in the absorption are not in the outer shell, and are thus less influenced by the surrounding electric field in the host crystal. Yellow apatite is the only gemstone in which the didymium lines are seen at all strongly.

COLOURLESS STONES

Naturally enough, most colourless or nearly colourless stones do not show absorption bands, since in such stones the 'colouring' oxides which produce such bands are absent. Colourless zircons, however, do show characteristic lines, too faint and narrow to affect the colour; and off-white diamonds and synthetic rutile have absorption bands in the violet.

White Zircon (*Uranium*)

There is invariably a narrow line in the red at 6535 Å, accompanied by a fainter line at 6590 Å, very close to it. Others of the prominent zircon lines seen strongly in most coloured zircons (5895, 5625 Å, etc.) are often visible. The spectrum is best seen by reflected light, as this enhances the strength of the faint bands.

Diamond (*Structure*)

Most diamonds show a narrow absorption band at 4155 Å in the deep violet which, when seen, is diagnostic for diamond. In 'Cape' stones this is very intense, and may be accompanied by five weaker bands at 4780, 4650, 4510, 4350, and 4230 Å in the blue

and violet. Of these weaker bands the 4780 band is the most prominent. Diamonds of the 'brown' series may show a fine line in the blue-green at 5040 Å with fainter lines at 5370 and 4980 Å, but these are very difficult to see. On the whole, stones showing a 'Cape' spectrum have a blue fluorescence under ultra-violet light, while diamonds of the brown series have a green fluorescence. A blue (copper sulphate) filter will be found to make lines in the deep violet more easy to observe.

Synthetic Rutile

This spectacular synthetic gem has not yet been made free from colour. The yellowish tint is probably due to the presence of a powerful absorption band in the violet (about 4250 Å) which terminates the spectrum.

RED STONES

Ruby (*Chromium*) *Figure* 47 (1)

Natural and synthetic stones have the same spectrum, though since synthetics contain more chromium for a given depth of colour the spectrum lines in these tend to be more intense.

The ruby spectrum is a rich and complex one, but the distinctive features are clear enough. These are: a strong doublet in the deep red, at 6942 and 6928 Å, seen under normal conditions as a single *bright* fluorescence line; two fainter lines on the orange side of this (6680 and 6595 Å), which also may appear as fluorescence lines; a strong, broad absorption band, centred near 5500 Å, covering most of the yellow and green, and three narrow bands in the blue, two of which are close together, the other distinctly separated, at wavelengths 4765, 4750, and 4685 Å. There is strong general absorption of the violet. The fluorescence doublet is a sensitive test for traces of chromium in corundum. As little as 1 part of Cr_2O_3 in 10,000 Al_2O_3 in the corundum lattice will give rise to a red fluorescence in strong white light, ultra-violet light, or X-rays. One may thus see this bright line in the spectrum of many nearly colourless sapphires, and in blue sapphires from Ceylon in which there is a trace of chromium and not enough iron to damp the effect. In chrome-rich rubies or synthetic rubies the doublet may be seen as an absorption line in direct transmitted light. In Siam rubies, in which enough iron is present to 'damp'

the fluorescence, the brightness of the fluorescence line is correspondingly diminished. This does not, however, provide a foolproof method of distinguishing between stones from the two main ruby localities. A copper sulphate filter assists in the observation of the fluorescence lines, as these are then seen against a dark background. It also helps one to see clearly the lines in the blue.

Ruby is strongly dichroic, and its absorption spectrum thus differs according to the direction in which the light travels through the stone. The main difference is seen in the broad central absorption band, which is much broader and more intense in the ordinary ray, thus giving it a purer red than the yellowish-red of the extraordinary ray.

The only other red gemstone with which ruby may be confused on the basis of its absorption spectrum is spinel. Spinel also shows a red fluorescence exactly similar in colour to that of ruby, but the spectroscope analyses this into a series of bright lines, giving an organ-pipe effect in contrast to the appearance of one bright line accompanied by two much fainter lines on the orange side of this, which is seen in ruby. Another decisive distinction is the absence of lines in the blue in spinel.

This spectrum has been discussed at some length on account of its importance and interest. Even so, many of the subsidiary lines sometimes seen in the ruby spectrum have not been mentioned. To sum up, one can state that any red stone which, when illuminated shows a bright fluorescence line in the red *and* narrow absorption lines in the blue is undoubtedly a ruby, either natural or synthetic.

A good idea of the nature and position of the absorption bands in ruby and the other spectra described hereafter will be gained by a study of the drawings specially made for this edition by Mr T. H. Smith, which are reproduced in Figures 47–50. Unlike most drawings which have been given in books, these are shown as through a prism spectroscope since the author is convinced that for general identification purposes this form of spectroscope is the best to use. The wavelength scale above the spectra reveals how the red end of the spectrum is cramped and the violet extended when using a prism instrument.

For convenience in drawing, the doublet in the deep red is shown here as an *absorption* doublet, which will only be the case when a deeply coloured ruby or synthetic ruby is viewed by light

which has been transmitted through the stone in a strictly direct beam. In ordinary practice the observer sees this as a *bright* line in exactly the same position. By juggling with the direction of the light passing through the stone under test it is often possible to see the change from dark line to bright line taking place.
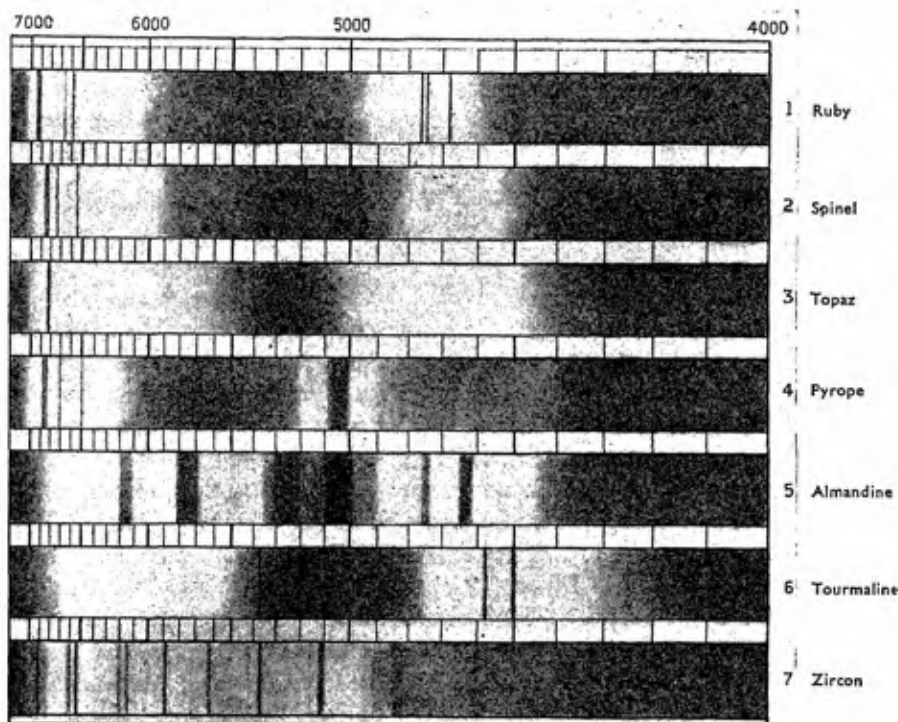
Figure 47.—Absorption spectra of red stones as seen through a prism spectroscope

Red Spinel (*Chromium*) Figure 47 (2)

Apart from a broad absorption band in the green, centred at 5400 Å, bands or lines in spinel are rarely noticeable, though in chrome-rich types from Burma a number of fine lines may be seen in the red. Red or pink spinels, however, can usually be determined with certainty on account of their very distinctive red fluorescence lines in the deep red. Unlike ruby, these form a group of five or more, reminiscent of a series of organ-pipes. Two central

lines are brighter than the others: strongest of all is that at wavelength 6860 Å, which is separated by a dark gap from the next most prominent line at 6750 Å. To see this distinctive series of lines clearly it is essential to use a really powerful light source. A copper sulphate filter is also very helpful, as it shows the lines against a dark background. It is interesting to note that the seldom seen synthetic red spinels, whether made by the Verneuil process or by some other process of crystallization (see page 86), do not show the 'organ-pipe' structure, but have their red fluorescence chiefly centred in a single line at 6860 Å. When viewed through the spectroscope there is then a resemblance to ruby with these freak synthetics—but absence of absorption bands in the blue is a sure sign that they are not ruby.

Almandine Garnet (*Iron*) Figure 47 (5)

The spectrum of almandine is one of the easiest to see and to recognize. With zircon, it shares the distinction of being the first gemstone in which dark bands were observed and recorded. This was in 1866, when Sir Arthur Church wrote an account of his discovery in a letter to the *Intellectual Observer*.

The main feature of the almandine spectrum is the presence of three broad, strong bands in the yellow (5760 Å) green (5270) and blue-green (5050). There are several weaker bands, notably one in the orange(6170) and one in the blue (4620). Of the three main bands, the one at 5050 is the most persistent, and can be faintly seen in almost all pyropes, as described hereunder, also in many spessartite garnets, especially those from Ceylon. Almandine has no fluorescence.

Pyrope Garnet (*Chromium and iron*) Figure 47 (4)

The pure magnesium-aluminium garnet would presumably be colourless but such a mineral is never found in nature. All red garnets, in fact, are mainly mixtures of the almandine and pyrope molecules. For convenience we term those with low index and density 'pyrope' and those richer in iron, having higher refractive index and density, 'almandine'. But it so happens that the pyropes most used in jewellery (from Kimberley, Bohemia, or Arizona) owe their rich colour more to chromium than to iron. This gives rise to a broad band in the yellow-green centred near 5750 Å,

which swallows two of the three main almandine bands which would otherwise be visible. The third almandine band at 5050 Å can be seen rather faintly where the green merges into the blue. As with spinel, narrow chromium lines are seldom seen in the red. Distinction between pyrope and red spinel spectra should be easy. As iron is present in quantity, pyrope has no fluorescence, and the broad central absorption band is at the yellow end of the green, whereas in spinel it is 350 Å 'further down' towards the blue.

Pink Topaz (*Chromium*) Figure 47 (3)

Pink topaz, or the sherry-coloured topaz from Ouro Preto which turns pink after heat-treatment, contains enough chromium to cause a red fluorescence between crossed filters, and this resolves itself through the spectroscope into a rather weak fluorescence line (probably a doublet) at 6820 Å. In large and deep-coloured stones this may be seen as an absorption line, though never at any great strength. The topaz spectrum may not be very reliable as a diagnostic aid, but it is rather important for the gemmologist who uses a spectroscope to know that pink topaz, under strong illumination, may show a narrow bright line in the red—otherwise he might mistakenly think such an effect must indicate pink sapphire. When the two are compared, there should be no confusion since, apart from a wavelength difference of 100 Å, the brilliance and sharpness of the fluorescence doublet in pink sapphire are incomparably greater, and two other, weaker fluorescence lines can be seen on the orange side of the strong doublet.

Red Tourmaline (*Manganese*) Figure 47 (6)

Red and pink tourmalines usually show two rather narrow bands in the blue at 4580 and 4500 Å. These are not so narrow as the rather similar bands in ruby, they are much further towards the violet, and of course there is no fluorescence line in the red— so there is no real excuse for confusion between the two. In certain brownish red tourmalines there is, in addition to the broad absorption band in the green which appears in all red tourmalines (indeed in all red stones), a narrow band at 5370 Å appearing within the broad band towards its long-wave margin. This narrow band is not strong, but helps to make this spectrum completely diagnostic for this type of tourmaline. The absorption

curves of pink and red tourmalines seem to show that their colour is largely due to manganese.

Red Zircon (*Uranium*) Figure 47 (7)

Though some red zircons show the distinctive narrow band in the red at 6535 Å, its fainter companion at 6590, and some ten other narrow bands distributed throughout the spectrum, due to uranium, there are some (notably those from Expailly) which show no bands at all. The drawing given shows the full spectrum. Wavelengths of these bands will be given in the description of the yellow zircon spectrum, which is more constant and reliable.

Of the other red or pink stones found in jewellery which show absorption bands one may briefly mention red pastes owing their colour to selenium, which have only a broad band in the green which varies in position according to the type of glass used, and the two translucent ornamental pink stones, rhodonite and rhodochrosite. These both owe their colour to manganese and have very similar spectra. Normally only a broad band in the green centred near 5500 Å can be seen. Transparent specimens of rhodochrosite, which are very rare, show a band in the violet at 4490 Å and an intense band at 4100 in the deep violet. Transparent rhodonite shows a narrow band at 5030 Å, a vague band at 4550 Å, and very strong narrow bands at 4120 and 4080 Å. These spectra have little practical value, but are interesting in their relation to the spectrum of spessartite, the manganese garnet, the spectrum of which will be found under 'yellow stones'.

ORANGE STONES

Fire opal is the only true orange gemstone, and as such does not comfortably mix with any other coloured gem. It has no absorption bands beyond a general absorption of the whole spectrum except the red and orange. Orange glass shows a very similar effect, except that the cut-off to the spectrum is rather more sudden.

Orange synthetic sapphire, sometimes known as 'padparadsha', always contains some chromium, and thus shows the fluorescence line described under ruby. Spessartite often has a peculiar reddish yellow colour that might be described as orange—but this spectrum has been included under 'yellow stones'—which will now be dealt with.

Yellow Zircon (*Uranium*) Figure 48 (1A)

Yellow to brown zircons from Ceylon show a strong and very distinctive spectrum of narrow bands distributed remarkably evenly throughout the spectrum. The strongest bands are at wavelengths 6910, 6625, 6590, 6535, 5895, 5625, 5375, 5150, 4840 and 4325 Å. These and fainter bands can be seen in the drawing reproduced as Figure 48. Golden-yellow zircons produced by heat treatment of brown crystals found in Indo-China do not show so strong or full a spectrum. But the 6535 band and its fainter 6590 companion can always be seen, as narrow 'pencil lines' in the red. It should be remembered that the 'reflected light' technique should be used where bands are too faint to be easily seen in transmitted light.

Yellow Sapphire (*Iron*) Figure 48 (2A)

Yellow sapphires from Australia, Siam, or Montana contain enough iron to show quite strongly the group of three bands in the blue which are at their full strength in green sapphire. The strongest of these is at 4500 Å, and this may be seen faintly even in some Ceylon yellow sapphires, which contain very little iron. The other bands are at 4600 and 4710 Å. The last-named band can always be seen as distinct from the other two, which tend to coalesce when at full strength. It is important to be able to distinguish this threefold complex band from the solid block of absorption which is seen (at shorter wavelength) in chrysoberyl. In addition to proving the stone to be a yellow sapphire, these bands, when seen, are also a guarantee that the stone is not synthetic. Synthetic yellow sapphires are coloured with nickel, not iron, and show no absorption bands.

Yellow Chrysoberyl (*Iron*) Figure 48 (3A)

Pale yellow, golden yellow, greenish yellow or brown chrysoberyl all show a broad band at the beginning of the violet region, centred at about 4440 Å. The strength of this band increases with the depth of colour of the stone: it is, in fact, the main producer of the colour seen. In strongly-coloured stones, two weaker and narrower bands may be detected in the green-blue region at 5050

and 4850 Å. The band at 4440 can often be seen in the highly-prized chrysoberyl cat's-eyes, thus distinguishing them beyond doubt from their cheaper rivals, cut from chatoyant quartz.
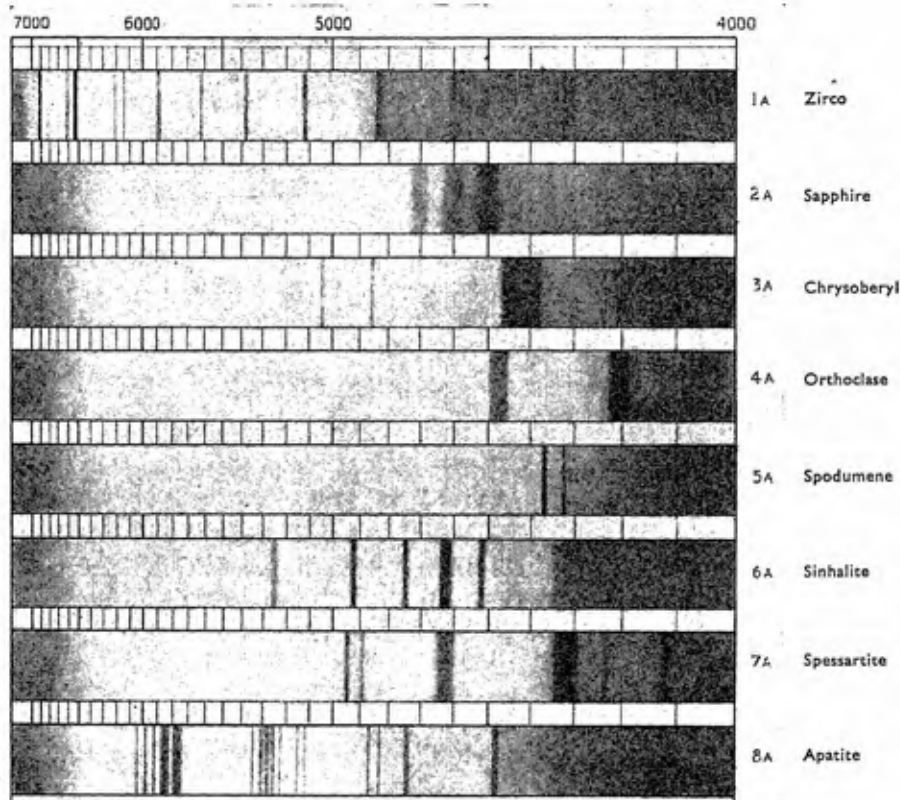
Figure 48. *Absorption spectra of yellow stones*

Yellow Orthoclase (*Iron*) Figure 48 (4A)

Yellow orthoclase from Madagascar makes quite an attractive gem. Its colour is due to ferric iron replacing some of the alumina in the feldspar, and this gives rise to two rather vague bands in the blue and violet, wavelengths 4480 and 4200 Å, the latter being the stronger.

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Yellow Spodumene (*Iron*) Figure 48 (5A)

Yellow spodumene also owes its colour to ferric iron. It shows two quite narrow bands in the violet at 4380 and 4325 Å, which are almost exactly similar to those seen in jadeite, which has a closely analogous formula. The 4380 band is considerably stronger than its companion.

Spessartite Garnet (*Manganese*) Figure 48 (7A)

The rare manganese garnet, spessartite, is seldom pure yellow, having usually an orange tinge, or even a hint of red, owing to admixture with other garnet molecules. Almandine bands are often faintly visible, especially the persistent 5050 band. The specifically spessartite bands include two rather feeble bands at 4950 and 4890 Å, a stronger one at 4620 in the blue, and a powerful band at 4320 Å. Where visibility extends as far, two further narrow bands may be seen at 4240 and 4120 Å, the latter being very intense. This may be a puzzling spectrum to the beginner, but when seen in a stone which from its refractive index one might expect to be an almandine, it does serve to prove the presence of important amounts of manganese, and enable one to place the garnet with certainty into its correct category.

Sinhalite (*Iron*) Figure 48 (6A)

Although sinhalite is a 'new' gemstone in the sense of having only recently been given a name and a formula, it has been fairly extensively cut as a gemstone in the past, and specimens, formerly mistaken for zircon, chrysoberyl or peridot, keep cropping up. The most attractive specimens are a golden yellow with greenish tinge. The spectrum is very similar to that of peridot, but there is an 'extra' band in the blue at 4630 Å, which is missing in the peridot spectrum. There is a weak band at 5270 Å, the main bands being at 4930, 4750, 4630 (mentioned above) and 4500 Å. The spectrum ends with what may be a further band at 4360 Å.

Yellow Apatite (*Didymium*) Figure 48 (8A)

Though brittle and rather soft, yellow apatite can make quite an attractive collector's gemstone. It is one of several yellow stones containing essential calcium in which traces of the rare earth elements known as didymium are present, giving a characteristic

narrow-line spectrum. Didymium bands are very similar in type and position in whatever medium they occur; thus they do not form so positive a basis for identification as do bands due to the presence of transition elements. But the spectrum in apatite is so much more intense than in danburite or in sphene, for instance, that it does virtually serve as a diagnostic for the mineral. The strongest didymium lines form a group in the yellow, with prominent members at 5840 and 5780. Another group of lines in the green has its centre near 5380 Å. The drawing in Figure 48 gives a good idea of this complex and beautiful spectrum.

GREEN STONES

Emerald (*Chromium*) Figure 49 (1B)

Emerald shows a typical chromium absorption spectrum, with a strong doublet in the deep red at 6835 and 6806 Å. The two narrow lines forming this doublet are twice as far apart as those in ruby, and can thus just be separated by a small prism spectroscope. Two weaker and more diffuse lines appear at 6620 and 6460 A, and beside each of these is a narrow region of high transparency, giving a curious and characteristic appearance to the spectrum. Another line at 6370 Å is at its strongest in the ordinary ray, being then almost as strong as the doublet. There is a broad but rather weak absorption band in the yellow—leaving the green unabsorbed: hence the colour of the stone. In deep-coloured specimens a narrow line in the blue at 4774 Å may be seen in the spectrum of the ordinary ray.

Alexandrite (*Chromium*) Figure 49 (2B)

This is another typical chromium spectrum, with the lines more clearly defined than in emerald—sharper, perhaps, even than in ruby. In alexandrite the central broad absorption band which determines the colour is in a half-way position compared with the red ruby and the green emerald—hence its balance of colour between green (daylight) and red (tungsten light). The strong doublet in the deep red is at 6803 and 6875 Å, and is 'reversible' as in ruby, though not seen as a fluorescence line in ordinary circumstances. There are weaker lines at 6650, 6550, and 6450 Å. Narrow lines can be seen in the blue at 4730 and 4680 Å. There is sufficient resemblance with the ruby spectrum to cause possible

error if the spectrum is only carelessly examined, and the stone itself accepted as ruby on its appearance in artificial light only.

Jadeite (*Chromium and iron*) Figure 49 (3B)

Fine green jadeite owes its colour almost entirely to chromium, and typical chromium lines are seen in the red. There might be confusion here with translucent emerald, but in jadeite the lines are noticeably more diffuse. The doublet (not properly resolved) is centred at 6915 Å, and two weaker lines at 6550 and 6300 Å. There is strong general absorption of the violet end of the spectrum, but if the slit of the spectroscope be opened to allow more light through, a powerful band at 4370 Å can be detected lurking in the gloom. This is an iron band, and is seen at its best in the paler varieties of jadeite (white, lavender, pale green). It is narrow and well-defined, and can be seen in light reflected from the specimen: it thus forms a useful test for jade beads and ornaments. A similar but far weaker band may be detected at 4320 Å.

Green Sapphire (*Iron*) Figure 49 (4B)

The spectrum already described under yellow sapphire belongs in its full strength to green sapphire. Here the two strongest iron bands practically coalesce, but the third band (4710 Å) is sufficiently detached to reveal that the band is a complex one, and not a single block, as in chrysoberyl.

Green Chrysoberyl (*Iron*) Figure 49 (5B)

Green chrysoberyl gives merely a stronger version of the strong absorption band in the blue-violet already described under yellow chrysoberyl. This is centred at 4440 Å. Weaker bands may be seen at 5050 and 4850 Å. The 4440 band may often be seen in cat's-eyes, forming a useful means of confirming that they are not the less highly valued quartz cat's-eyes.

Peridot (*Iron*) Figure 49 (6B)

Peridot shows a very characteristic iron spectrum, the main feature of which is the series of three evenly spaced bands in the blue region. The first of these appears where the green changes to blue at 4930 Å. The second is at 4730, and the third at 4530 Å. The edges of the bands are diffuse, but there is a fairly well

defined 'core' to each—especially the first two. The appearance of these bands varies noticeably according to the vibration-direction of the light. The 'beta' spectrum is the strongest, and in this a weak band at 5290 Å can be detected.

Sinhalite (*Iron*) Figure 49 (7B)

This recently described 'new' gemstone has been already dealt with under 'yellow stones', but it is often greenish in cast. It is well to be clear of the difference between the spectrum of sinhalite and that of peridot, with which it was so long confused. The drawing reproduced in Figure 49 shows the two spectra side by side. The 'extra' band in sinhalite at 4630 can be clearly seen.

Enstatite (*Iron*) Figure 49 (8B)

An outstanding feature in the absorption spectrum of enstatite is a clear-cut, narrow band at 5060 Å. This is seen in tremendous strength in brownish stones from India, when weaker bands at 5480, 4830, 4500, etc. can also be seen. In the attractive green enstatites which, with fine red pyrope pebbles, were recovered from the diamond concentrates in Kimberley, the colour is enriched by the presence of chromium, and a doublet can be seen at 6870 and weaker chromium bands on the short-wave side of this in the usual chromium manner. In these green enstatites the 5060 band is still sharp and clear. There can be no doubt it is due to ferrous iron. This region of the spectrum, where green turns to blue, is often the position for the strongest iron band (cf. almandine, peridot, green tourmaline, diopside).

Chrome Diopside (*Iron, chromium*) Figure 49 (9B)

Attractive green diopside (often chatoyant) from Burma contains enough chromium to enrich the colour and show chromium lines in the red, with the doublet centred at 6900 Å. Narrow bands in the green-blue are reminiscent of enstatite, but here there are two lines in place of one, about equal in strength, the wavelengths being 5080 and 5050 Å.

Demantoid Garnet (*Iron, chromium*) Figure 49 (10B)

The most valuable and most attractive of the garnets, the green garnet demantoid, is a variety of the calcium-iron garnet

andradite. Here again we have an iron spectrum (ferric) with enough chromium to enrich the colour and show chromium lines in the red. The iron band is an intensely strong one, centred at 4430 Å. This is far enough into the blue-violet to be difficult to see as anything more than a sharp cut-off to the end of the spectrum, especially where chromium is present and causing
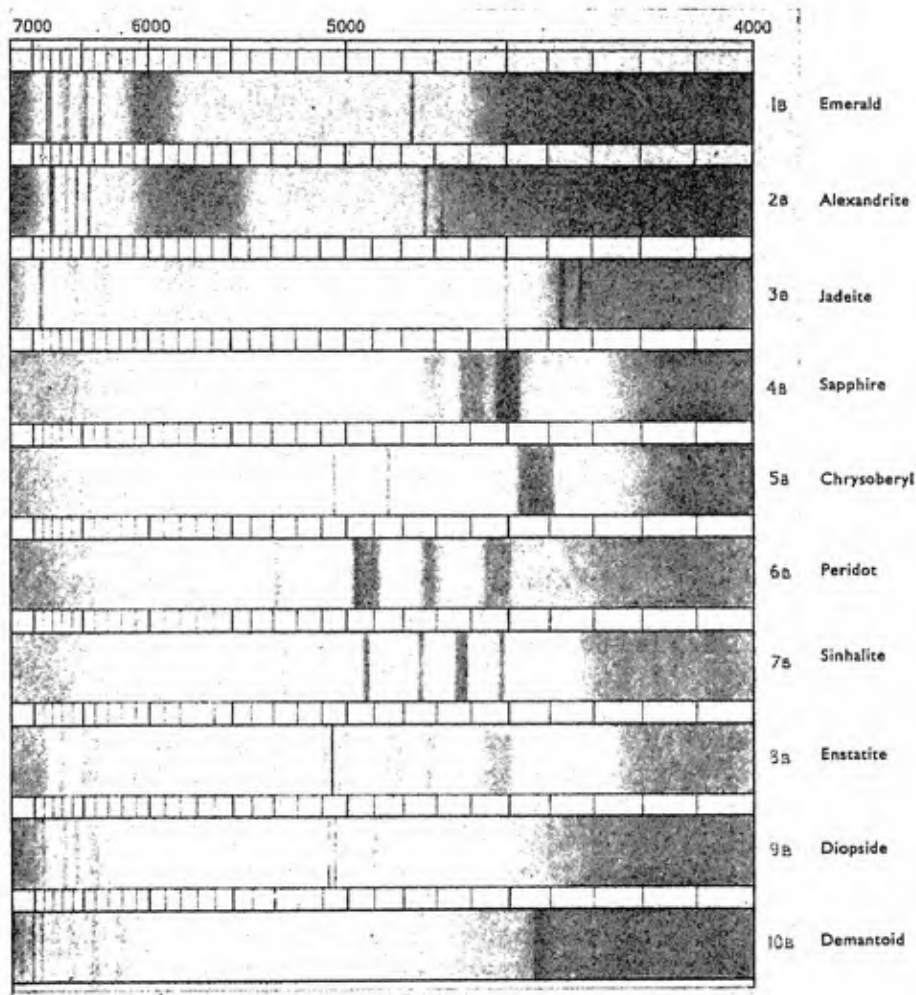
Figure 49. Absorption spectra of green stones

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general absorption of the violet. In paler stones, and with good lighting conditions, the band can be seen complete: though very strong it is not very wide. The chromium lines are easily seen in good specimens: the doublet is very deep in the red (7010 Å), and there are weaker and rather diffuse lines at 6400 and 6210Å.

Zircon (*Uranium*)

Green zircons can always be relied upon to show absorption bands, but the type of spectrum seen varies enormously with the degree of internal breakdown (metamictization) of the zircon crystal concerned. Most Ceylon green or greenish zircons show a strong ten or twelve band spectrum, with the strongest band in the red at 6535 and the other bands distributed throughout the spectrum as described under 'yellow zircon'. But even in these it will be noticed that the edges of the bands are 'woolly', and not sharply defined as in the fully crystalline 'high type' zircons. Such stones have usually a rather cloudy or sleepy appearance. In the really 'low type' zircon with density 4 or under and no appreciable birefringence there may remain only a diffuse and rather broad band near 6530 Å. In some low types, however, a narrow band at 5200 Å in the green is very noticeable. When heated, this peculiar type reveals a strong, anomalous spectrum, in which some other element in addition to uranium is obviously playing a part.

Zircons of rather dark brownish-green colour are found in Burma and these have suffered no metamictization and contain more uranium than those from Ceylon. The result is a spectrum showing not only the dozen or so of main zircon bands at great intensity, but other fainter lines between, bringing up the number to some forty bands in all, as seen through a small spectroscope. To the practised eye all the above variations on the main zircon theme spell 'zircon', especially when the appearance of the stone is taken into account. The key position to look for is the 6535 Å region in the red: where the other bands in the green and blue are seen also there can be no mistake. If these are missing, the beginner may confuse the narrow uranium bands for a chromium spectrum. But the strong chromium doublets are always far deeper into the red, and the accompanying features of each chromium spectrum are sufficiently distinctive to provide the necessary supporting evidence in case of doubt.

Green Tourmaline *(Iron)*

Tourmalines of full-bodied green or greenish blue absorb all the red part of the spectrum down to about 6400 Å. In that critical position where the green gives way to the blue a narrow absorption band can be seen (4970), which can be ascribed to iron.

Aquamarine *(Iron)*

Sea-green aquamarine is seldom used in jewellery now, the stones being usually heat-treated to produce a pale blue colour which is more popular. In green aquamarine and sometimes in other pale beryls a distinctive narrow line can be seen at 5370 Å in the green. This is only visible in the extraordinary ray (see also blue aquamarine).

Epidote *(Iron)*

Epidote commonly soaks up so much light that it can seldom be cut into an attractive gem. The colour is almost as much brown as green. The blue and violet are both strongly absorbed, but if enough light can be passed through, an intense band can be seen at 4550 Å, and one less intense at 4750 Å, in the blue.

Andalusite

The brownish-green andalusites resembling tourmaline which are those usually seen as gemstones may show a band in the blue at 4550 Å, but this is not very reliable as a test. This is probably an iron band. Quite a different spectrum is seen in a rare bright green type from Brazil. This is due to some unidentified rare earth, judging by the extreme sharpness and delicacy of the bands or lines. There is a sharp edge of shadow at 5525 Å in the green shading away to the yellow side, while on the other side is a narrow line at 5495. There is another line nearer the blue at 5175 Å, and general absorption of the blue and violet.

Fluorspar

Weak bands may be seen in green fluorspar at 6340 and 6100 Å in the orange, at 5820 Å in the yellow, and 4460 and 4270 Å in the violet. These bands may help to identify a large translucent fluorspar ornament or figure, which may be confused with emerald or jadeite. In cut specimens (which in any case are only collector's

items, as the stone is far too soft for wear) these bands may be too faint to be noticed.

Kornerupine

Only in fine specimens is this mineral attractive as a gem, and its rarity precludes its use in commercial jewellery. It is pleochroic, and the absorption bands vary considerably according to direction.

There is a band in the blue-violet at 4460 Å which is fairly strong in the 'beta' ray, and weaker bands at 5400 and 5030 Å in the green and 4630 Å in the blue. There is another weak band at 4300 Å in the violet. The bands are probably due to iron. The spectrum is not distinctive enough to form more than confirmative evidence of the identity of the mineral.

The list of absorption spectra shown by green stones could be extended still further, but all the most important and reliable instances have been given above. Those translucent stones which occasionally show bands (e.g. nephrite, Connemara marble, etc.) and are not mentioned above will be noted in the descriptive text later in the book where this is thought to be helpful.

<div align="center">BLUE STONES</div>

Sapphire (*Iron*) Figure 50 (1c)

One of the most important spectra in the whole series for the practising gemmologist is that of sapphire, for it not only proclaims the species of the stone, but also reveals whether it be natural or synthetic. The spectrum, which is due to iron, is seen at full strength in green sapphire and in varying strength in yellow sapphire, as has been described above. In blue sapphires the bands are again very variable in strength. Australian sapphires show all three bands quite strongly, while in Ceylon sapphires, which contain very little iron, only the 4500 Å band can be seen, and even this is often exceedingly faint. The band is an 'ordinary ray' band, and therefore shows at maximum strength in the direction of the optic axis. In a cut stone this direction may usually not be known, but it is worth while, if the band is only very faintly seen to turn the stone on edge and on end in attempt to see the band more strongly. A Polaroid disk turned to the correct angle over the eyepiece of the spectroscope may also help to increase the apparent strength of the band. Passing light through a copper sulphate

filter flask is here very helpful, enabling the observer to see any bands in the blue region with greater clarity. With synthetic sapphires, although iron oxide as well as titanium is used to produce the blue colour, virtually all the iron evaporates from the boule or is concentrated in the surface layers which are removed when cutting is carried out. Three very weak and vague bands in the blue have often been detected by the author in synthetic sapphires, the central one of these being very nearly in the same position as the 4500 band of natural sapphire. But there should be no confusion between the two, as it must be emphasized that the 4500 band is quite a narrow one when it is only faintly developed. Indications of the 4600 band to one side of the main band can also be seen in sapphires from any other locality than Ceylon, and this adds to the distinctiveness of the spectrum. It is well worth the gemmologist's while to practise the observation of this band, as it will save him much time and trouble in testing sapphire jewellery.

Blue Spinel (*Iron*) Figure 50 (2c)

The absorption spectrum of blue spinel is another which is well worth study. It is somewhat complex and difficult to describe, and may even vary a little in its nature from specimen to specimen. But when one has one's eye in, so to say, the nature and distribution of the bands are very distinctive. Indications of the 'blue spinel' bands can be seen in many purplish or brownish-red spinels also. The key bands to note are a broad one in the blue centred at 4590 Å and a narrow band of about equal strength at 4800 Å, on the green side of this. Rather elusive bands in the green (5550 Å), yellow (5920), and orange (6320) complete the pattern, and give the impression of quite a rich spectrum. Nuances of absorption which can hardly be counted as bands add to this impression of richness. Distinction between the blue spinel and sapphire spectra can be made with complete certainty by taking the trouble to apprehend the different nature and pattern of the bands in the blue, quite apart from their different wavelengths. Similarly, the vague bands in the green should not be confused with the cobalt bands in synthetic blue spinel. But possible mistakes of this kind should be borne in mind, and accessory tests carried out where the observer does not feel quite sure of himself.

Aquamarine *(Iron)* Figure 50 (3c)

Mention has already been made of the spectrum of green aquamarine. The blue aquamarine now so popular shows two rather ill-defined and weak bands in the blue (4560) and violet (4270). The 4270 band is fairly strong in large specimens (and aquamarines used in jewellery are usually large) while the other

7000	6000	5000	4000		
				1c	Sapphire
				2c	Spinel
				3c	Aquamarine
				4c	Iolite
				5c	Apatite
				6c	Turquoise
				7c	Tourmaline
				8c	Zircon
				9c	Synthetic Spinel
				10c	Cobalt Glass
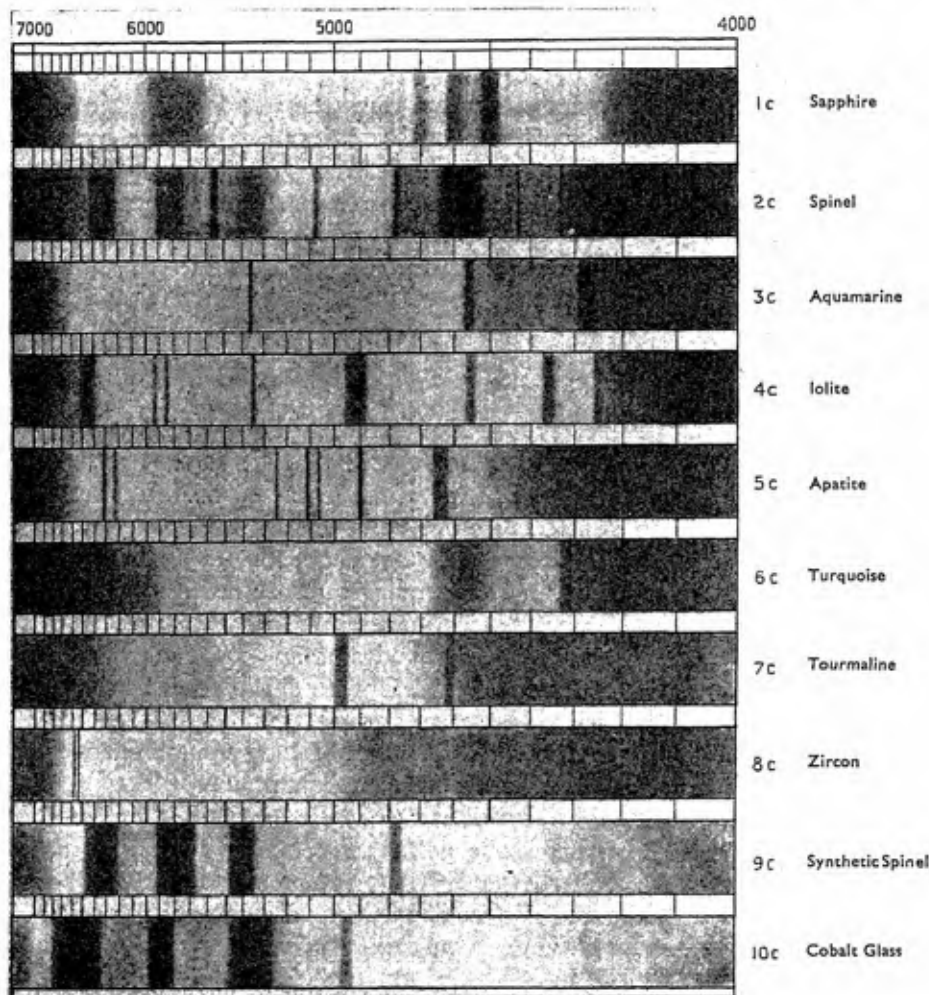
Figure 50. Absorption spectra of blue stones

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band, weak though it is, helps to make the spectrum recognizable. Aquamarine from the Maxixe mine has a most peculiar spectrum, with strong bands in the red at 6970 and 6570 Å, and a weaker band in the orange at 6280 Å. The cause of these bands is not understood. The narrow line at 5370 Å, mentioned under green aquamarine, does not seem to appear in the heat-treated blue types. In the drawing, this line has been included, however, to give an idea of its position and nature.

Iolite (*Iron*) Figure 50 (4c)

As one might expect in so pleochroic a gemstone, the absorption bands seen in iolite vary a good deal with direction. In the blue ray there are vague bands in the blue and violet regions at 4920, 4560, and 4370 Å. In the yellow ray there is a distinctive double band, each member being quite narrow, in the yellow region (5930, 5850). There is also a narrow band or line at 5350 Å, reminiscent in position and nature of the green aquamarine line mentioned previously.

Apatite Figure 50 (5c)

Curiously enough, blue apatite does not often show the didymium bands so typical of the yellow variety. Instead, there are bands at 6310 and 6220 Å in the orange, at 5110, strong and fairly narrow in the green, a strong band at 4900, and a broad, weak band at 4640. These bands belong to the 'ordinary' ray which is yellowish in colour when isolated, as it is in the direction of the optic axis.

Turquoise (*Copper*) Figure 50 (6c)

The absorption spectrum of turquoise, discovered by the author during the war years, has proved to be a most useful diagnostic feature in a gem material which is notoriously difficult to test. There are two bands of almost equal appearance and strength (as shown by a photograph) at 4320 and 4200 Å, of which only the 4320 can normally be seen. Only through thin edges is turquoise translucent enough to allow enough light through to render this violet band visible, but fortunately it shows very well by reflected light. There is a vague band in the blue at 4600 Å, which helps to provide a distinctive pattern for the mineral. No bands similar

to these have been seen in any minerals or counterfeits which resemble turquoise in appearance.

Tourmaline (*Iron*) Figure 50 (7c)

Blue tourmaline shows the same narrow band at 4970 Å mentioned under 'green tourmaline'.

Zircon (*Uranium*) Figure 50 (8c)

Blue zircon owes its colour to heat treatment of reddish brown rough. At least two of the strongest of the zircon lines—those at 6535 and 6590 Å—can be seen, as narrow 'pencil lines', especially when reflected light is used. Other of the main zircon bands may also show faintly in the yellow and green.

Synthetic Blue Spinel (*Cobalt*) Figure 50 (9c)

Cobalt-blue is never found in natural minerals, and when seen heralds the presence of some artificial product—notably blue synthetic spinel or cobalt glass. The cobalt absorption bands seen are very similar in each case, consisting of three broad main bands in the orange, yellow, and green, but in synthetic spinel the bands are more closely clumped together (see drawing) and the central band is the widest of the three, whereas in glass the centre band is the narrowest. Wavelengths of the synthetic spinel bands are 6350, 5800, and 5400 Å. The width and intensity of these bands vary proportionately to the depth of the blue colour. In deep blue specimens the bands almost amalgamate into a single block. Absorption of the yellow-green, together with free transmission in the deep red make these cobalt-coloured artefacts appear strongly red under the Chelsea filter.

Cobalt Glass (*Cobalt*) Figure 50 (10c)

The position of cobalt bands in glass varies a little with the composition of the glass concerned. Average measurements are 6550, 5900, and 5350 Å. The distinction between this blue glass and synthetic blue spinel by means of the spectroscope is easily made, according to the relative width of the central band, as mentioned above. Cobalt glass is often used as the base of blue garnet-topped doublets: the superposition of a faint almandine

spectrum on that of the cobalt glass may give a rather confusing effect unless the nature of the stone is apprehended.

All absorption spectra of any importance have been described above. In many of the species faint bands additional to those listed have been seen and measured, but these add nothing at all to the recognition of the stones in question. Those interested in complete descriptions will find them in a series of forty articles in the *Gemmologist* on 'The spectroscope and its applications to gemmology', which appeared from September 1953 to December 1956. An index to the series was given in the issue for January 1957.

Beginners are urged to confine their attention to simple spectra such as those of almandine and ruby and some zircons before attempting less well defined absorption effects. A really strong source of light and a properly adjusted and suitable spectroscope are the most important keys to eventual success in this beautiful and important method of gem testing.

9

THE IDENTIFICATION OF DIAMOND

THE description of the testing methods recommended has now been completed, and perhaps the hypothetical jeweller for whose assistance these chapters were written may be wondering how these tests may be applied in the actual specific cases which come into his daily routine. Our next task will therefore be to consider each of the more important precious stones from the standpoint: 'how may it be identified?' and 'what imitations or other stones may be mistaken for it?'

If we decide to deal in this manner with precious stones in order of their commercial importance, diamond must obviously be the first choice. Diamonds account for well over 90 per cent by value of the world's trade in gems, and the smallest jeweller in the meanest street has diamond-set rings to sell and, in however small a way, is a buyer and seller of diamonds.

Partly on account of this very universality and partly by reason of certain outstandingly distinctive features in its appearance, diamond is one of the few stones that almost any jeweller hopes to recognize with tolerable certainty by mere visual inspection.

There have been occasions, however, when costly mistakes have been made. Well cut colourless zircons, suitably mounted, and offered in a poor light by a plausible client, have often deceived even experienced pawnbrokers. Diamond doublets can also be very deceptive, and the new synthetic material, strontium titanate, presents a very diamond-like appearance. To be able to recognize these and the older substitutes (pastes, synthetic spinels, etc.) from diamond is an urgent necessity for any jeweller or dealer, and it will be useful, therefore, to describe clearly the various signs by which diamonds can be recognized, beginning with those which entail only careful scrutiny with the naked eye or a pocket lens, and proceeding to those which involve the use of some form of apparatus. The distinguishing features of all the possible diamond substitutes can then be related.

The distinctive appearance of diamond itself is due to the combined effect of its 'adamantine' surface lustre, the perfection of its polished surface, its brilliance and its 'fire'. These are bound

up with its supreme hardness, high refractive index, and dispersion—also the skill with which it is cut.

The proportion of light reflected from the surface of diamond is higher than that for any other natural colourless stone, and this, combined with its hardness and the superb flatness and high polish of the surfaces prepared by the skilled diamond cutter, gives rise to the peculiar 'adamantine' lustre which belongs to diamond alone. Synthetic rutile may reflect more light, and strontium titanate as much light as diamond, but their softness does not permit so flat and mirror-like a surface to be prepared, nor such sharp angles between the facets. If one tilts a diamond until the reflection of window-bars or of an electric light bulb be seen in the table facet, it will be noticed how free from distortion the reflected image is.

Diamonds are so fashioned that practically all light entering the front of the stone is totally reflected from the back facets as from a series of mirrors (the rays striking them at angles greater than the 'critical angle', which for diamond is only $29\frac{1}{2}°$). Thus a well cut brilliant, viewed from the back and held up to the light, will show only a pin-point of light from the culet, and nothing more. Also, looking down on a brilliant-cut diamond mounted in a ring, one cannot (because of this total reflection effect) see the wearer's finger below the stone, as one usually could in the case of stones of lower refracting power.

Further, white light entering a diamond is dispersed into its spectrum colours to a considerable degree, giving flashes of pure colour from the smaller crown facets. This 'fire' in diamond, combined with its superb optical purity, constitutes one of its main claims to beauty.

The high refractive index of diamond makes the stone appear much shallower than it really is when viewed through the table facet; and this, together with the fact that the refraction is *single*, forms another distinguishing sign.

Other revealing features which can often be detected with a lens are small portions of the original crystal surface, remaining on the girdle. These 'naturals' hardly affect the beauty of the stone, and are often purposely retained by the diamond cutter to enable him to know at a glance the direction of the 'grain' while the diamond is being cut and polished. Tiny 'nicks' in the girdle can also often be detected, and these may show flat, angled surfaces

which follow the planes of perfect octahedral cleavage of the diamond. The inclusions, too, are frequently distinctive, shining flakes of graphite or other forms of 'carbon' being perhaps the commonest of these.

So much for examination by eye or lens: now for some specific tests.

Hardness

Hardness is a quantity difficult to define and to measure in gemstones, and hardness tests should normally be avoided where more accurate tests, less liable to damage the stone, can be applied. But the case of diamond is unique. More than 100 years ago, when Mohs devised his 'scale' of scratch hardness (which has proved so useful that it is still in constant use by mineralogists and gemmologists), he designated diamond as hardness 10. Next on the scale came corundum (sapphire) with hardness 9. Although artificially prepared abrasives such as silicon carbide (carborundum) and boron carbide exceed corundum in hardness, and the recently-prepared high-pressure form of boron nitride ('borazon') may even equal diamond in hardness, diamond still remains the only gem material which can scratch ruby or sapphire.

Polished pieces of synthetic corundum are not difficult to obtain, and, failing these, any lapidary can provide a polished piece of natural poor-quality sapphire for a few shillings. If a facet edge or girdle of a diamond be applied carefully but firmly to the surface of a polished corundum 'test piece', it will be found to 'bite' and to leave a decided scratch-mark, which will not disappear when rubbed with a moistened finger. By this simple procedure the stone will have been proved beyond doubt as a veritable diamond, and, with reasonable care, no harm can come to the stone tested, whether it be diamond or not. Strontium titanate, a new synthetic material which closely resembles diamond and has virtually the same refractive index, is very soft (not much more than 5 on Mohs' scale) and a gentle touch with the point of a steel needle will leave a mark on the surface of one of these stones.

Refractive index

Diamond is also remarkable for its high single refraction (2·42), and though this is not unique it still forms a valuable test. The highest reading obtainable on a standard refractometer is limited

to 1·81 by the contact liquid used. Diamond will thus give a 'negative' reading, though it would be unwise to place a stone thought to be a diamond on a refractometer, as damage to the soft glass of the instrument is difficult to avoid when so hard a stone is applied.

Only three other natural gemstones giving negative readings are likely to be encountered. These are zircon (1·926 to 1·985), demantoid (1·89) and sphene (1·90 to 2·03). Of these, only zircon is colourless, and only demantoid is singly refracting. With a lens, zircon and sphene show strong doubling of the back facets, while demantoid shows typical 'horsetail' inclusions.

In recent years, two substances have been artificially prepared which match or exceed diamond in refractive index. These are synthetic rutile with indices 2·61 and 2·90, and strontium titanate, which is singly refracting and has an index (2·41) very near to that of diamond. Rutile can at once be recognized by its huge double refraction and its stupendous 'fire', which causes it to flash with colour almost like an opal. Also, at best, rutile has a distinct yellowish tint, even when a thin film of sapphire has been deposited on the stone by a special sputtering or evaporation process, to improve its hardness and appearance. Strontium titanate resembles diamond much more closely: it is nearly colourless and is singly refracting. But this, too, has an excess of 'fire' by diamond standards, and a comparison between the two reveals this difference at once. In a mounted stone, the high density of this new synthetic (5·13) cannot aid one as a test. A careful hardness trial, using a steel needle, as indicated above, is very practical. Inclusions when visible, may be distinctive, and, in common with all the imitations of diamond, strontium titanate lacks the transparency to X-rays that is so notable a feature of diamond.

Refractive index forms the basis for the distinction of diamond from the more common and long-established synthetics, colourless sapphire, and spinel. These are often used for 'diamond' clusters or surrounds in cheap jewellery. The stones may well be too small to place easily on a refractometer, but immersion of the whole piece of jewellery in methylene iodide will immediately show that the suspected stones are not diamond. Both sapphire and spinel virtually 'disappear' in this liquid, which approaches them so closely in refractive index, while diamond will still show its facet edges in clear relief.

Fluorescence

The fluorescent glow emitted by diamond under short- or long-wave ultra-violet light is very variable, but often distinctive, and forms a useful test on many occasions. This is particularly true in the case of an ornament containing many diamonds. Placed under a quartz mercury lamp with a Wood's glass filter, or under a 'black bulb' lamp which incorporates such a filter, some of the diamonds will be seen to emit a bright sky-blue fluorescent light, others a feebler effect, while some may seem almost inert. A stone or two may show a yellow or yellow-green fluorescence. If such an ornament shows either no fluorescence or a uniform fluorescence of any kind, then the stones are certainly not diamond. Of course

Figure 51. *X-ray photograph of diamond and zircon rings*

the varied fluorescence effect does not prove that all the stones present are true diamonds, but it gives a very strong supposition that such is the case. Mr Robert Webster has suggested that a photograph of the 'pattern' formed by diamonds fluorescing in different degrees in a piece of jewellery would form a unique record of that piece, and could be used for identification purposes in case of loss or theft.

Under X-rays diamonds show fluorescence of more uniform intensity—usually some shade of blue. If the blue glow from a fluorescing diamond is sufficiently strong the banded nature of the fluorescent light can be seen with a prism spectroscope (with slit opened rather wide) and then constitutes a definite proof that the stone is diamond and not some other blue-fluorescent material. The important 4155 Å absorption band appears as a fluorescent bright line in blue-fluorescent diamonds. Similarly the 5040 Å

absorption line seen in brown or green diamonds is also the wavelength of the strongest of a series of fluorescence lines in green-fluorescing diamond. In both blue- and green-fluorescing diamonds, however, there are wide regions of continuous spectrum emitted by the glowing stone.

One of the many interesting observations on diamond made by the Bangalore school of physicists under Sir C. V. Raman was that strongly blue-fluorescing diamonds have a yellow-green afterglow when removed from the exciting ultra-violet radiation. The writer has tested this on numerous occasions and found it to be invariably true. The phosphorescence quickly decays and can easily escape notice, but if the stone is held in cupped hands and, immediately after removal from the rays, the eye applied thereto, the cupped hands making a small, completely dark chamber, the glow of the diamond can be quite easily detected. Green-fluorescing diamonds also show phosphorescence, and the strength of the afterglow is usually proportional to the strength of the original fluorescence. This afterglow in diamond provides a useful check that a blue-fluorescing gemstone is indeed diamond.

Though the 'constants' of diamond are seldom used for testing purposes, even by laboratory workers, they should be stated here. The *density* of gem diamond is usually given as 3·52, and this is a good working value. Careful measurements on fine diamonds have established 3·515 as the most accurate figure. Nearest to this among possible 'rivals' is the density of sphene (3·53) but the double refraction, pleochroism, and low hardness of this mineral do not allow for any real confusion with diamond. More worth noting is that white topaz pebbles, which are often assumed to be diamond by hopeful prospectors and amateur collectors, have a density near 3·56, though one low value of 3·545 was recently obtained by the author. The fact that topaz pebbles are water-worn, while diamond never is, and the lack in topaz of the distinctive diamond lustre should preclude any false hopes when topaz is encountered in the field.

The *refractive index* of pure diamond is 2·4175 for sodium light. For diamonds of ordinary gem quality we have found 2·4190 to be a more usual figure. Here the value for the new synthetic substitute strontium titanate, is very close. Our results on several specimens have shown 2·410 to be an average figure, which in itself is too close to diamond to form a distinctive test. But since

such a measurement could only be obtained by minimum deviation, with the stone set up to act as a prism on a table spectrometer, there would be no necessity to confine the measurement to the sodium yellow line. Were shorter wavelengths used, such as the green line of thallium or the blue line of lithium, the vastly greater dispersion of strontium titanate compared with diamond would at once become apparent.

Though diamond is justly famed for its 'fire', its *dispersion* of 0·044 for the B-G interval is in fact unusually low for a stone of such high refractive index. Sphene (0·051), demantoid (0·057), and cassiterite (0·071), with much lower indices, all exceed diamond in dispersion, while for those stones of comparable index zinc blende with its dispersion of 0·156 and strontium titanate with 0·180 must be considered normal. To most people's taste, however, the degree of fire shown by diamond is amply sufficient to give it beauty, while strontium titanate and synthetic rutile look opalescent and gaudy by comparison.

An outstanding property of diamond which is very useful for the laboratory worker is its transparency to X-rays. This is due to the low atomic weight of carbon (12). A few seconds exposure to X-rays of any doubtful stones, resting on a photographic plate or film will show a startling difference between the very radiable diamond and strontium titanate, synthetic rutile, zircon, or paste —all of which contain heavy atoms and are opaque to the rays. The beginner at this method should always place known stones alongside for comparison. Incidentally, X-ray photography is a useful test for the valuable type of industrial diamond aggregate known as carbonado, which is much sought after for its extreme toughness, allied to the supreme hardness of diamond. This material resembles coke to the uninitiated eye. Radiographs give a good idea of the diamond content of a given sample, which can also be checked by density measurements. There is a variation from about 3·10 for low-grade specimens to about 3·50 for those which are nearly entirely composed of diamond.

As stated in Chapter 8, most diamonds show a narrow absorption band in the deep violet at 4155 Å when light which has been transmitted through them is examined through a suitable spectroscope. This band is particularly intense in off-coloured specimens of the 'Cape' series, and in definitely yellowish stones is accompanied by other bands, the strongest of which is in the blue at

4780 Å. Diamonds of the 'brown' series, which often have a green fluorescence, may show a narrow absorption line at 5040 Å, with fainter lines near this.

During the foregoing account of the properties of diamond, most of the possible substitutes have been mentioned and their relevant properties indicated, but it may be useful at this point to run through the whole list, indicating the discriminative features of each.

Any question of **synthetic diamond** can be left for the far future: only minute grains have so far been produced by the new G.E.C. process mentioned in Chapter 6. The materials we have to consider are **white zircon, synthetic rutile, strontium titanate, synthetic white spinel, synthetic white sapphire, diamond doublet,** and **paste** (lead glass) imitations. **Sphene** and **demantoid garnet** might also possibly be confused with coloured diamond.

White zircon is the only natural colourless stone with sufficient 'fire' to pass for a diamond amongst the unwary or the inexperienced. The majority of fraud cases involving so-called diamond rings sold in public-houses and the like have turned on the fact that zircon has a certain resemblance to diamond. To the gemmologist the distinction could hardly be more simple. The strong double refraction of zircon makes doubling of the back facet edges obvious under a good 8 or 10 × lens, and a test with the spectroscope can be used in confirmation. **Synthetic rutile** has even greater double refraction, and its tremendous fire makes it full of opalescent colours; moreover its body colour is never free from a yellowish tinge, and its surface has a greasy lustre compared with the hard clean-looking surfaces presented by diamond. **Strontium titanate** has much more serious claims to be an effective substitute, being nearly free from colour, singly refractive, and with virtually the same index of refraction as diamond. Its softness, however, imparts a certain greasiness to the surface polish, and forms an effective test if a needle point be carefully applied —while the fact that the dispersion, though less than that of rutile, is still four times that of diamond gives it a false and over-coloured appearance to the informed eye. Strontium titanate has no fluorescence under ultra-violet light, and is opaque to X-rays. Tiny 'centipede' surface markings are often visible. (See Chapter 6.) It is only possible seriously to confuse **synthetic white sapphire**

and **synthetic white spinel** with diamond when they are cut as small baguettes or very small brilliants and mounted in jewellery, though it should be remembered that synthetic spinel formed the basis for an absurd 'synthetic diamond' scare in 1935. Where a refractometer reading is possible, a sure means of identification is possible in each case. Where small mounted stones are in doubt the whole piece can be immersed in methylene iodide. In this liquid both sapphire and spinel will show very low relief, the facet edges practically disappearing. Diamonds, on the other hand, will stand out almost as boldly as in air, with their facet edges plainly visible. For distinguishing between the two categories of synthetics a test between crossed polarizers is helpful. Synthetic white sapphires will transmit light except in the four extinction positions, while synthetic spinels will show the peculiar and characteristic form of strain-birefringence to which the writer has given the descriptive term 'tabby extinction'. Diamond, it should be noted, also shows strain birefringence between crossed polarizers, as mentioned later in the chapter. **Natural white sapphires** are seldom free from some tinge of colour, but are sometimes used as a substitute for diamond in native jewellery.

Diamond doublets are occasionally seen, and can be puzzling, though they do not look quite 'right'. Usually they consist of a crown of diamond cemented to a pavilion of white synthetic sapphire, quartz, or even glass. Such composite stones are usually met with in a mount, and as the crown of the stones shows the typical surface lustre, inclusions, and general appearance of diamond, it is easy to accept them as poor-quality genuine stones unless one's suspicion is aroused. At a certain angle the edges of the table facet can be seen reflected in the surface formed by the junction layer. Under the microscope, bubbles may also be seen in this layer. Immersion in methylene iodide will make the refractive index difference between the crown and pavilion of the stone very obvious (see Chapter 6).

Lead-glass imitations of diamond (commonly known as 'pastes') can make a very effective display when they are new and well cut, and these are very extensively used in 'diamanté' costume jewellery. They are seldom intended to deceive, and the poor quality of their surface polish, their glassy lustre, and their softness, all reveal their nature. The refractive index of these glasses varies, but is usually between 1·62 and 1·68. The refraction

is of course single, and under the microscope glassy bubbles and often 'swirl marks' are visible.

On account of their high refractive index and appreciable fire, the yellow or brown **sphene** and green **demantoid garnet** might be mistaken for coloured diamonds. Sphene has distinctively strong double refraction and pleochroism, while the singly refracting demantoid has a powerful absorption band in the violet and almost invariably shows fibrous 'horse-tail' inclusions which are an effective aid to its identification.

COLOURED DIAMONDS

The question of coloured diamonds has assumed new importance because of the modern practice (at present confined chiefly to the U.S.A.) of inducing colour in off-coloured stones by submitting them to some form of atomic bombardment. Perfection colour in diamond is a complete absence of colour, unless it be a hint of blue, perhaps provided by the blue fluorescence of a colourless stone. But, on account of their rarity, there has always been a market, amongst those who can afford such luxuries, for diamonds of decided hue. Of these, yellow 'canary' diamonds and brown 'cinnamon' diamonds are the best known—though even of these perhaps only a few hundred are found in the millions of stones mined annually—while very few indeed are known which have a pronounced green, blue or red colour. To-day, either by bombardment with neutrons in an atomic pile, or by charged particles from a cyclotron, diamonds of commercially unfavoured yellowish tint can be turned green, and stones of brown or golden yellow hue can be produced from these by subsequent careful heating. By electron bombardment, stones of distinctly blue or bluish green colour can be obtained.

These changes in colour are ascribed to 'radiation damage', that is, to the displacement of atoms in the diamond crystal, leaving gaps in its structure which affect the absorption of light.

Since the beginning of the century, following experiments by Sir William Crookes, it has been known that the colour of diamond could be changed to green by exposure to radium or its salts. Quite a number of stones were so treated, and retain their colour to the present day. What is more surprising is that the treated stones also retain a marked radioactivity, emitting chiefly 'alpha particles' (helium nuclei) with a range in air which indicates that

they are emitted by polonium, one of the later products of radium emanation. Crookes was unable to destroy this radioactivity by treatment with acids or even fused alkalis, and it would seem that a proportion of radioactive atoms were able to penetrate to a minute degree below the surface of the stone, where their disintegration continues. Lind and Bardwell found that the colour of radium-treated stones could be removed by heating for several hours at 450° C, or by recutting the stone.

Figure 52. Auto-photograph of brilliant and drop-shaped radium-treated diamonds. Sixty hours exposure on bare plate

The radioactivity of these radium-treated stones made them very easy to test, since in contact with a photographic film or plate they yield an 'autoradiographic' image in a few hours, and produce scintillations on a suitable zinc-sulphide screen. Incidentally, the radioactivity was sufficiently strong to cause skin damage to anyone who wore such a stone constantly in a ring.

The modern irradiated stones are no longer perceptively radioactive, except for a few hours after they have been treated, so that simple test is no longer operative. In the case of green stones, the colour tends towards the dark bluish-green of tourmaline, and is not like any hue seen in natural diamonds. The yellows and browns are more convincing in appearance, but can usually be detected by abnormalities in their absorption and fluorescence characteristics. As for blue diamonds, Dr J. H. F. Custers, of the Diamond Research Laboratory in Johannesburg, maintains that all natural

blue diamonds belong to an unusual structural type, which he designates 'Type IIb', which have certain characteristic properties, including transparency to ultra-violet light down to a wavelength of about 2500 Å, phosphorescence under short-wave ultra-violet rays, and behaviour as semiconductors. Treated stones will not have these properties, and the 'make up' of the colour is spectroscopically not the same as in the rare natural blue stones.

Much work will have to be done before these colour-changes,
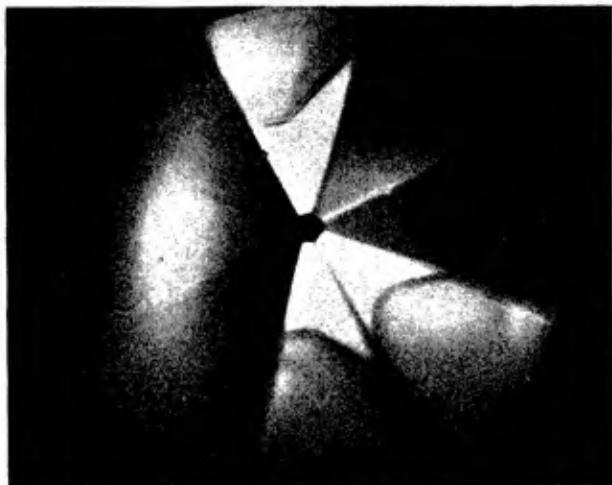
Figure 53. 'Umbrella' colour-margin seen near culet in cyclotron-treated diamond. When seen, this is proof of a treated stone

or indeed the causes of colour in natural diamonds, are properly understood.

Robertson, Fox, and Martin were the first to discover (1934) that diamonds can be divided into two main categories according to their transparency to ultra-violet light, their infra-red absorption, and various other properties. The commoner type (designated Type I) are transparent to about 3000 Å only and are usually blue-fluorescent to a greater or lesser degree. The rarer 'Type II' diamonds are transparent to about 2250 Å and are for the most part non-fluorescent.

Dr Custers has found that Type II diamonds can be further

subdivided into Type IIa stones, which will not phosphoresce and will not conduct electricity, and Type IIb stones, which are phosphorescent under short-wave ultra-violet light and can carry a strong electric current when under a potential difference of 100 volts.

Stones transparent to short-wave ultra-violet light are not so rare as some authorities imagine. For instance, of four flat 'portrait stone' diamonds in the author's collection three transmit below 2500 Å, and only one cuts off at the 'normal' wavelength of near 3000 Å. These four stones also exemplify another fact—
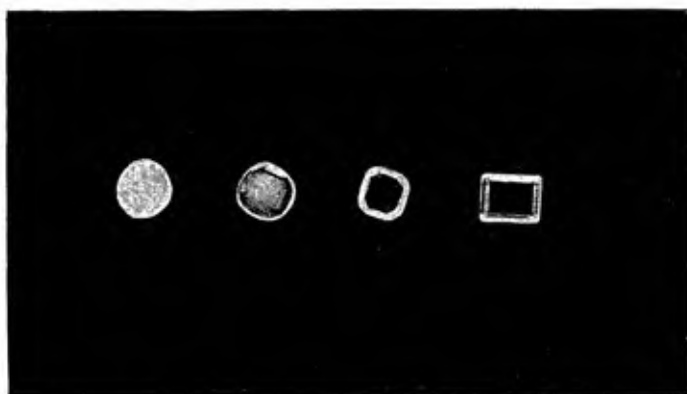
Figure 54. Variations in transparency to short-wave ultra-violet light shown by four portrait-stone diamonds (see text)

that there are intermediate degrees of transparency which do not neatly fit into either category. This is clearly demonstrated in the photograph reproduced in Figure 54. The four stones were placed on contact paper in a dish of water and exposed for a few seconds to rays from a short-wave ultra-violet lamp with Chance OX 7 filter, and the paper developed. This gave a negative image, so that the rectangular stone on the right of the picture with its dark centre represents the stone most transparent to the rays.

It might be thought that these strange differences in diamond (unaccompanied, it may be said, by any difference in appearance) are of purely scientific interest, and are out of place in a book devoted to simple methods of gem testing. But they may have

practical importance in the distinction between stones which owe their colour to atomic bombardment and stones which are naturally coloured. If it is true, for instance, that all natural blue diamonds belong to Dr Custers' IIb category, then any blue diamond which is a non-conductor and is opaque to short-wave light (thereby showing itself to be a Type I diamond) must owe its colour to electronic bombardment. J. R. Gowering Shield, of the New York Gem Trade Laboratory, has found that brown and yellow diamonds owing their colour to bombardment followed by heat treatment are distinguished by a narrow absorption line at

(a) (b)

Figure 55. Diamonds between crossed Polaroids, showing strain birefringence: (a) Type I, (b) Type II

5920 Å, in the yellow, which is very rare indeed in naturally coloured stones.

The properties of diamond and its possible substitutes are tabulated below. Topaz and quartz are added to the list, though their lack of brilliance and fire make it very unlikely that they would be confused with diamond. The properties of paste vary considerably in accordance with its composition, but the data for a representative specimen of good quality are included in the table. In the last column are listed figures for dispersion, which give a numerical basis for the effect of 'fire'. The figures represent the difference between the R.I. of the stone in question for violet and for red light (B-G in the solar spectrum). The value for the dispersion of

rutile is approximately that for the ordinary ray; for the extraordinary ray it is even higher. The value for strontium titanate is estimated.

Diamond and its Possible Substitutes

Stone	H.	S.G.	R.I.	D.R.	Disp.
Diamond	10	3·52	2·42	none	0·044
Zircon	7½	4·69	1·926–1·985	0·059	0·039
Syn. rutile	6¼	4·25	2·610–2·900	0·287	0·300
Strontium titanate	5½	5·13	2·41	none	0·180
Corundum	9	3·99	1·760–1·768	0·008	0·018
Syn. spinel	8	3·63	1·727	none	0·020
Topaz	8	3·56	1·612–1·622	0·010	0·014
Quartz	7	2·65	1·544–1·553	0·009	0·013
Paste	5	3·74	1·635	none	0·031

THE IDENTIFICATION OF RUBY

AFTER diamond, the most important precious stones from a commercial standpoint are ruby and sapphire which, despite their very different appearance, are both varieties of the same mineral species, corundum. Let us consider ruby first, and see by what simple means it can be recognized and also by what tests the other stones which to a certain degree resemble it may be distinguished.

Corundum is simply crystallized alumina (Al_2O_3) and, when quite pure, is entirely devoid of colour. The rich hue of ruby is due chiefly to small amounts of chromic oxide, which is able to replace part of the alumina without disturbing the hexagonal crystal structure. The source for the world's finest rubies has always been the Mogok district in Burma, where so many other interesting gem minerals are found. Rubies from Siam, owing to the presence of traces of iron, tend to have a less attractive colour, resembling garnet, and are not popular in the trade; while rubies from Ceylon are often more pink than red. Nevertheless, fine rubies from these less-regarded districts are occasionally found, and should be sold as such, on their merit. To vary the price of a stone, not on account of its quality but on account of its fancied origin, is one of those illogical habits which the trade would do well to eradicate.

The properties of an average Burma ruby may be briefly stated as follows: hardness, 9 (next to diamond on Mohs' scale); refractive indices, 1·765 and 1·773; double refraction, 0·008; density, 3·99 to 4·00. The dichroism is quite strong, the twin colours being pale yellowish red and deep carmine, and the absorption spectrum is highly diagnostic notably by reason of the narrow *bright* line (doublet) seen in the deep red and the narrow dark lines in the blue when the stone is powerfully illuminated. The former is due to the bright red fluorescence of ruby, but the distinction from **Synthetic ruby**, which also has the properties so far mentioned, has still to be considered.

If the necessary apparatus is available, the above properties render the identification of ruby a simple matter. Apart from this the materials most likely to be confused with genuine ruby are

spinel, garnet, tourmaline, pastes, and **doublets.** A careful refractometer reading using either sodium light or a good red colour filter is in itself conclusive, since the only red stone in which the refraction is similar is garnet. Only pyrope garnet, with a *single* index between 1·74 and 1·75, approaches the best ruby in colour, though other garnets of the almandine–pyrope series, having higher indices, may be confused with Siam rubies where colour is the only guide. Perhaps the simplest test to apply, though not so conclusive, is the test for dichroism, remembering always that it is essential to tilt the stone and examine it from different angles to get the strongest effect. Spinel, garnet, paste, or the ordinary doublet will show no trace of dichroism, and the only dichroic red stone apart from ruby is the rubellite variety of tourmaline, which seldom, if ever, is seen in the same shade of red as corundum. The dichroic colours of red tourmaline, dark red and pink, are, however, rather similar to the colours seen in Burma (and synthetic) ruby, noted above.

Another simple aid to the recognition of ruby is its appearance under the Chelsea colour filter. Viewed through the filter, under a bright light, ruby shows a peculiar vivid fluorescent red, and this, combined with its dichroism, should leave little doubt in the mind of the observer, even if a refractometer is not available.

The red fluorescence of ruby is a spectacular sight under ultra-violet light (quartz-mercury lamp with Wood's glass filter)—but visible green, blue, or violet light will also stimulate this fluorescence in ruby; hence the appearance of the bright fluorescence doublet when examining the spectrum of the stone, and its fluorescent red appearance when viewed through the Chelsea colour filter. A splendid exhibition of the fluorescence of ruby and synthetic ruby is provided by viewing specimens between 'crossed filters'—the stones being illuminated by strong blue light through a flask containing strong copper sulphate solution, and viewed through a good red gelatine filter. None of the blue light can pass through the filter, but the red fluorescent glow from ruby most certainly can: stones are thus seen glowing like coals against a dead-black background—a sight so beautiful that it still delights the author after years of repetition. Red spinel shows a bright red fluorescence under the same conditions, which to the unaided eye is quite indistinguishable from that of ruby. The spectroscope, however, enables the two species to be separated with certainty.

In ruby, the red glow is seen to consist almost entirely of light from the strong doublet at wavelengths 6942 and 6928 Å, which appears as a single line in a small prism spectroscope. In spinel, there appears a whole group of bright lines, rather like a set of organ-pipes, with the two strongest in the centre of the group. This 'organ-pipe' fluorescence is a very sensitive test for spinel. No other red stones, garnet, zircon, tourmaline, nor any red pastes or doublets, show any red fluorescence.

Even if we have assured ourselves that the stone examined is indeed a ruby, we have still the important question to answer—
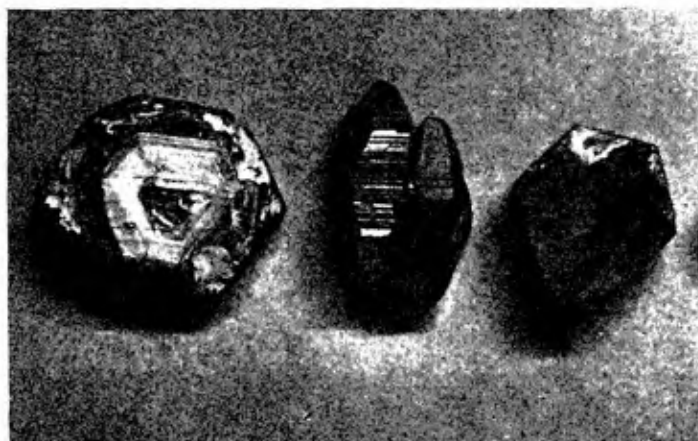
Figure 56. Crystals of sapphire and ruby (sapphire on left polished to show hexagonal zoning)

'is it a natural or a synthetic stone?'—since in all the physical properties already mentioned the **synthetic ruby** does not differ appreciably from the natural. The whole question of the discrimination between native rubies and sapphires and their synthetic counterparts manufactured by the Verneuil inverted blowpipe process has already been discussed in Chapter 6, but since the problem is one which so constantly worries the jeweller a few more words on the subject may be welcomed.

In the first place it is well to recollect that flawless rubies of rich colour and important size are, in nature, extremely rare. This fact alone should make one suspicious of a large clear specimen of unknown origin.

In most cases the mere appearance of the stone is enough to warn the trained observer that a stone is synthetic. This is partly due to a slight but real difference in the nature and proportions of the colouring oxides present in the stone, but is perhaps mainly due to the fact that a synthetic ruby is seldom cut in such a manner as to display the best colour. The most attractive colour in ruby is seen in the direction at right angles to the basal plane of the crystal, which is the direction of the 'optic axis'—that is, of single refraction and *no dichroism*. Thus in a properly cut ruby strong dichroism should not be observable directly through the table facet when the stone is viewed with the dichroscope. In a synthetic stone, owing to the shape of the original boule, the direction of cutting is almost invariably wrong, so that the fine purple-red of the 'ordinary ray' is diluted with the unpleasant yellowish red of the 'extraordinary ray', and the two tints can be seen side by side in the two images of the dichroscope window when looking directly through the table facet.

Another point to realize is that a natural ruby is hardly ever quite 'clean', which is to say that it almost always encloses small crystals of other minerals in the form of pale angular grains, cavities of irregular shape, often relatively large, and patches of fine criss-crossing canals, or of fine reddish rutile needles, which give a silky effect by reflected light and in consequence are known as 'silk'. When the presence of either of these forms of inclusion can be detected with a lens there can be no doubt that the stone is genuine. Care must be taken, however, not to confuse the crystalline inclusions mentioned with the spherical or elongated *gas bubbles* which are often a feature of synthetic stones. These are seldom so large in size as the crystals enclosed in Burma ruby, and under the lens are more likely to appear as little clouds of dust-like particles. Sometimes a dense cloud of microscopic bubbles may cause a milky reflection not unlike the 'silk' seen in natural stones.

The distribution of colour is also revealing: a curious feature of the natural Burma rubies is the presence of patches of deeper colour in the form of wisps and swirls to which the name 'treacle' has been aptly applied. Even a hint of 'treacle' in a stone is a sure sign of its genuine origin. Certain other stones owing their colour to chromium sometimes show a rather similar effect—e.g. red spinel, pyrope, and emerald. Synthetic ruby, when it is viewed with a lens or microscope in the right direction, always reveals

the finely spaced *curved* structure lines which represent the successive layers of growth of the boule as it grew under the blowpipe flame. All these internal features can be recognized with far greater ease and certainty under even the simplest form of microscope, which in addition opens up a whole new world of interest and beauty, for indeed the inclusions in most gemstones, and particularly in ruby, are both extremely interesting and extremely beautiful. If is of great assistance in studying internal features to immerse the specimen in a glass-bottomed cell containing a highly
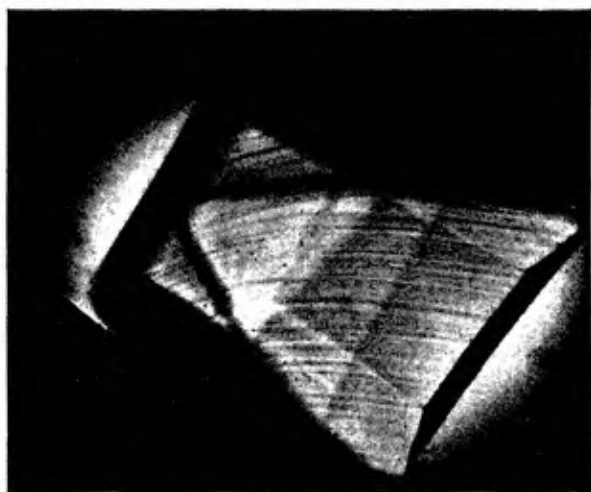
Figure 57. Curved lines in small synthetic ruby

refractive liquid such as monobromonaphthalene. If the specimen is a synthetic free from bubbles one must rely on finding the curved lines and this may entail examining the stone out of its setting at several angles until the lines become visible. The curves are usually more clearly seen when the lighting is not too brilliant, and the mirror of the microscope should be tilted to get the most marked effect, and the condenser lowered.

In reconstructed rubies, which are sometimes still met with in old jewellery, the curved lines are much more pronounced, and by no means rigidly parallel. The photomicrograph reproduced in Figure 57 shows the curved lines in a small synthetic ruby (0·10 carat) held obliquely by a strip of foil. For comparison, a

Figure 58. Unusual bubble formations and gas-filled tubes
in synthetic ruby
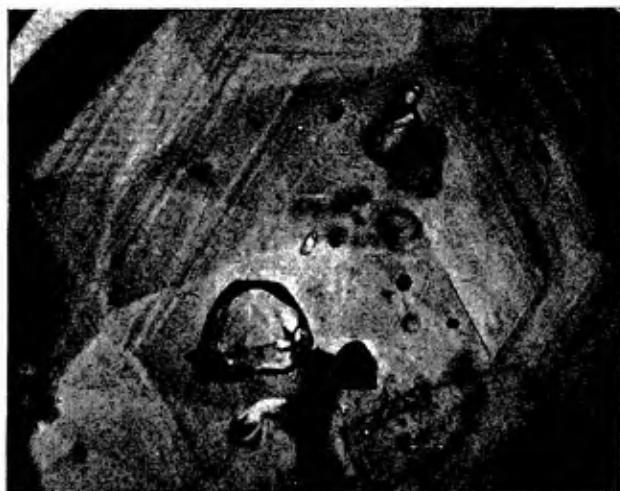
Figure 59. Crystal inclusions and zoning in Burma ruby

photomicrograph of a small Burma ruby is shown (Figure 59) in which not only the relatively large crystal inclusions can be seen but also *straight* lines of zoning parallel to the hexagonal outline of the original crystal. (See also Figures 19 and 21.) Sometimes only very small inclusions may be present, and these may easily be mistaken for bubbles by an inexperienced worker. In all difficult cases it is wiser to submit the stone for a laboratory test.

Laboratory workers are fortunate in having other tests in reserve where necessary. Under X-rays, for instance, both ruby and synthetic ruby show a red glow due to fluorescence, as they do under ultra-violet light or between crossed filters. But when the

Figure 60. Opaque crystals surrounded by liquid feathers, which are the most typical inclusions in Siam ruby

rays are cut off, there is a marked difference between synthetic and natural. With the natural stones the glow stops immediately and completely when the stimulus of the rays is removed, but with synthetic rubies there is a persistent afterglow or phosphorescence. To ensure that this effect will be visible, it is necessary to work in the dark and observe the stone with dark-adapted eyes.

The greater transparency of synthetic ruby to short-wave ultra-violet light has already been described in Chapter 6 and provides another most valuable background test in those few cases where there is still some uncertainty after an examination under the microscope.

The only natural stone resembling Burma ruby at all closely in colour is the red **spinel**, which is found in the same district. The colour in this case is also due to chromic oxide, but the tint is more brick- or orange-red than true ruby-red. In any case, the lack of dichroism in spinel and its single refraction (R.I. 1·72), different absorption spectrum and inclusions serve to distinguish it with complete certainty. When testing a parcel of rubies under the microscope, it is surprising how obviously different in colour an 'intruder' spinel appears and how noticeable is the dichroism in ruby if the stone is turned in the tongs.
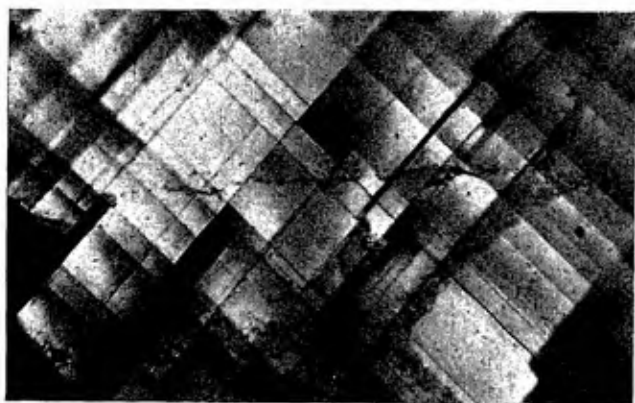
Figure 61. Twin planes in Siam ruby

The colour of red **garnets**, apart from certain pyropes already mentioned, is closer to that of Siam ruby. Garnets of this type have a very characteristic absorption spectrum containing three broad bands crossing the yellow, green, and blue parts of the spectrum, respectively, and this, apart from other tests, provides a very rapid and sure means of identification. **Tourmaline**, the only other natural stone that need be discussed in this connection, has far lower refractive indices (1·62 and 1·64) than ruby, and a larger double refraction, which latter property will enable the practised observer, using a lens, to detect a 'doubling' of the edges of the back facets of the stone if viewed through the front at a favourable angle. (See Chapter 19.)

Red **glass imitations**, which generally owe their colour to

selenium, are not very often encountered since the advent of synthetic ruby. Their lower, single refractive index, which is usually near 1·68, their lack of dichroism and their softness, all serve to distinguish them from ruby. Red **doublets**, almost invariably composed of a thin slice of almandine garnet serving as the table facet fused to a red glass base, are still sometimes seen. The table facet usually gives a refractive index reading of about 1·79, and the back facets about 1·63. Careful scrutiny with a lens will reveal the junction between the two layers as a thin line girdling the facets of the crown just below the table. The line in itself might not be noticeable, but there is an abrupt change in lustre between the garnet and the glass surfaces at the junction

Table for Identifying Red Stones

Stone	H.	S.G.	R.I.	D.R.	Dichroism
Ruby ...	9	3·99	1·76–1·77	0·008	strong
Zircon ...	7½	4·69	1·92–1·98	0·059	weak
Almandine	7½	3·9 to 4·2	1·76 to 1·81	none	none
Pyrope ...	7¼	3·7 to 3·9	1·74 to 1·76	none	none
Spinel ...	8	3·60	1·72	none	none
Topaz ...	8	3·53	1·63–1·64	0·008	distinct
Tourmaline	7	3·04	1·62–1·64	0·018	strong

between the two which is completely revealing when viewed at the correct angle. Though the garnet slice is very thin, the absorption bands of almandine can usually be detected in the spectroscope when light has passed through the stone. Detection of the fake is easy if the stone be viewed from the side while immersed in a liquid, against a white background. A highly refractive liquid such as monobromonaphthalene is best, but even an egg-cup full of water will serve the purpose very well. Under the microscope the doublet, if examined through the table facet, may show rod-like crystal inclusions in the almandine layer, followed by bubbles of air in the glass base and at the junction between the two layers.

A tabulated list of red stones which might be confused with ruby, so far as appearance goes, is given above, together with the

most important physical and optical properties which serve to distinguish between them.

Zircon is included in the list above for completeness, though red zircon bears no close resemblance to ruby. **Topaz** is also given, as deep pink topaz might be confused with pale Ceylon ruby of the type which grades into the so-called 'pink sapphire'. **Almandine** garnet could only be mistaken for the Siam ruby. The dichroism of the latter is by no means strong, but distinction from almandine is easy if a refractive index reading is taken carefully in sodium light, since the double refraction of ruby will then be clearly seen. The absorption spectrum of the garnet is also easy to recognize.

THE IDENTIFICATION OF SAPPHIRE

As IN the case of ruby, the most effective substitute for natural sapphire is its **synthetic** counterpart, and methods for detecting the differences between the natural and the manufactured stone will be found below, although the whole subject of synthetics has already been dealt with in Chapter 6. **Synthetic blue spinel** must also be considered in this connection. The other fraudulent substitutes for sapphire, **pastes** and **doublets**, are not so frequently encountered. As for natural blue gemstones, **blue spinel**

Figure 62. Typical zircon inclusions in Ceylon sapphire

and **blue tourmaline** are not uncommon, and exceptional specimens of these minerals may be mistaken for sapphire, though the blue of spinel is a greyish blue, and indicolite tourmaline is commonly a deep greenish indigo-blue in colour.

The rare gemstones **kyanite, benitoite**, and **iolite** resemble sapphire more closely so far as colour goes, but these are collector's stones scarcely seen in commercial jewellery.

In distinguishing between natural and **synthetic sapphire**, the same general methods are used as with synthetic ruby. The refractive index and specific gravity will not effect a separation, and the most reliable tests involve an examination of the internal features of the stone. With sapphire, mere inspection with the naked eye is usually sufficient if the stone be immersed in a liquid

such as monobromonaphthalene and viewed against a white background. In fact an egg-cup full of water will often suffice to show the distribution of colour, which in synthetic sapphire is always in the form of curved bands, whereas in the natural stones such banding is straight in zones parallel to one or more of the hexagonal prism faces in the original crystal (Figure 57). The curved bands in synthetic sapphire are more easily detected than in synthetic ruby, since they occur in broad swathes (Figure 27) of colour, whereas in ruby they are closely spaced and difficult to

Figure 63. Liquid 'feather' in Ceylon sapphire

detect with the naked eye. The gas bubbles, which in groups, swarms, or as isolated individuals, are a typical sign of all synthetics made by the Verneuil process, are also usually to be found in synthetic sapphire.

Natural stones on the other hand almost invariably carry within them clear signs of their slow crystallization in an environment consisting of chemically complex liquors and mineralizing agents. It is only to be expected that some of the substances surrounding the growing crystal should become impounded and remain preserved within the sapphire as frozen witnesses for our interrogation aeons later. These positive signs, included in native sapphires, apart from the straight zones of colour already mentioned, vary somewhat according to the locality where the sapphire was

mined. Thus, Ceylon sapphires contain typical 'feathers' consisting of layers of minute crystalline or liquid inclusions which reflect the light from one plane, often slightly curved, like a thumb-print (as shown in Figure 63). Other typical inclusions of Ceylon sapphires are rounded crystals of zircon, showing high relief and surrounded by crack-like haloes. 'Three-phase' inclusions, containing liquid, a movable gas bubble, and well-shaped crystals of haematite or other minerals, are also not uncommon in
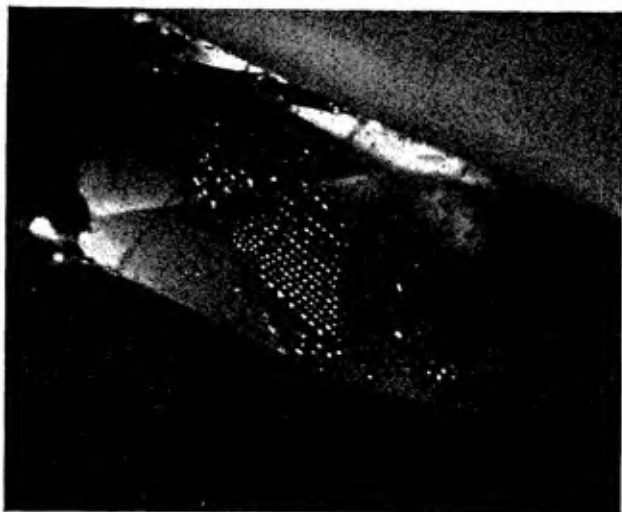
Figure 64. Crystal 'feather' and twin-planes in natural sapphire

Ceylon sapphires. (See Figure 65.) Siam sapphires resemble Siam rubies in frequently containing rounded opaque crystals surrounded by a disk-shaped lacy feather. Kashmir sapphires owe their attractive milkiness to minute liquid inclusions and contain typical feathers of small dimensions.

One test, which is often very valuable in checking on the natural origin of a sapphire in which clear signs are lacking, is to examine, by means of a small prism spectroscope, light which has passed through the stone. The manner in which this can best be done has been explained in Chapter 8. Most natural sapphires show a narrow absorption band in the deep blue of the spectrum, and sometimes a group of three bands, the strongest being at 4500 Å. If this band is detected, the stone is undoubtedly genuine, since

no synthetic stone has been known to show any absorption bands of this nature. Australian sapphires invariably show all three bands strongly, while Montana, Siam, Kenya, Kashmir, and Burma stones show them in diminishing strength in that order. In some Ceylon stones even the 4500 Å band is virtually absent, but these frequently contain a trace of chromium, and then show the bright red fluorescence doublet of ruby by scattered light. (As a warning, it should be said that some synthetic sapphires also show a red fluorescence.)
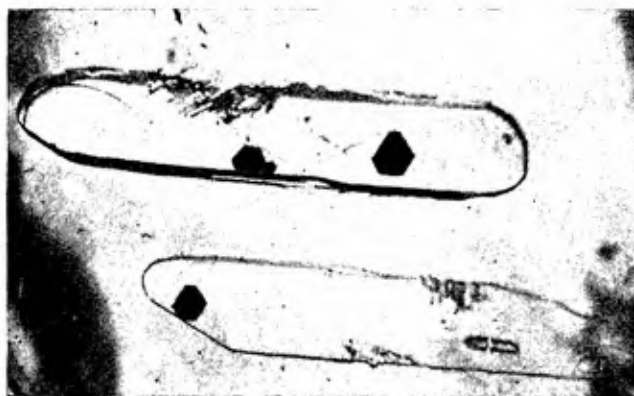
Figure 65. Three-phase inclusions in Ceylon sapphire (see text)

Besides synthetic sapphire, **synthetic spinel** of a deep royal blue colour is sometimes used to simulate sapphire. This fake can usually be detected by mere inspection, since in artificial light or sunlight red reflections from some of the back facets can be seen, owing to the presence of a considerable amount of red in the cobalt-blue which is the colouring agent. This also causes such stones to appear deep red under the Chelsea colour filter—a similar effect being noticeable in **blue pastes** when these are coloured with cobalt, and in **blue doublets** in which the table facet is garnet and the remainder a cobalt-blue glass.

Some glass imitations, however, are not coloured by cobalt but by iron, etc., and these are not to be detected by the filter. Blue synthetic spinel is of course also easily distinguished from sapphire by its lack of dichroism and by its single refractive index of 1·727. A warning note should perhaps be entered here. Ceylon sapphires frequently contain a trace of chromic oxide, and these

will tend to appear red under the Chelsea filter. Effects seen through the filter must in fact never be accepted blindly as complete proof of the nature of the stones concerned, but only as valuable indications. (See the full account in Chapter 4.)

Of the natural blue stones mentioned as possible substitutes for sapphire, **spinel** and **tourmaline**, the refractometer provides the best and most certain test. It should be mentioned that natural blue spinel may appear somewhat reddish through the colour filter, distinctly different from the dark greenish colour shown by sapphire, and also quite distinct from the full-bodied red seen

Table for Identifying Blue Coloured Stones

Species	H.	S.G.	R.I.	D.R.	Dichroism
Sapphire	9	3·99	1·76–1·77	0·008	strong
Benitoite	6½	3·67	1·75–1·80	0·047	strong
Kyanite	4–6	3·69	1·71–1·73	0·016	strong
Synthetic spinel ...	8	3·63	1·727	none	none
Spinel	8	3·60	1·72	none	none
Tourmaline ...	7	3·10	1·62–1·64	0·020	strong
Iolite	7	2·59	1·53–1·54	0·009	strong

with the synthetic blue spinel. **Star sapphire** and its substitutes will be dealt with in Chapter 20.

A table giving the constants of the various blue stones is given above, including the very rare benitoite and kyanite for the sake of completeness. **Benitoite** is a pretty, bright blue stone showing considerable 'fire'—its dispersion is actually as high as that of diamond. The largest cut stone outside museums weighs little more than a carat. Its refractive indices are near those of sapphire, but the double refraction is so much greater that there should be no confusion on the refractometer. **Kyanite** of a fine blue colour is occasionally cut, but the very easy cleavage gives such stones a characteristically flaky look quite different from the hard bright polish taken by sapphire. **Iolite** has an attractive deep violet-blue tint when viewed in the correct direction: in another direction it is a pale smoky yellow. This amazing dichroism gives rise to one of its alternative names—'dichroite'. Cordierite is another accepted name for this mineral.

IDENTIFICATION OF EMERALD

THE variety of beryl known as emerald shares with ruby and sapphire the rank of 'precious stone' in the popular estimation, and, as with the corundum gems, its rarity and costliness have served to stimulate man's ingenuity in providing artificial substitutes. Just as the red of ruby and the blue of sapphire cannot properly be matched by any other natural mineral, so is the pure emerald green unequalled by any other transparent natural gemstone.

Beryl is a silicate of beryllium and aluminium, and the colour of emerald is due to traces of chromium, which replaces to a small extent the aluminium ions in the crystal lattice of the hexagonal beryl crystal. It is a feature of this colouring agent, which also causes the red in ruby and in spinel and the betwixt-and-between colour in alexandrite, that even when it produces a green colour it transmits a proportion of deep red light. Chromium is also the cause for the red fluorescence that can be seen in all these gemstones, when suitably stimulated. It is for these reasons that the majority of emeralds appear red or reddish when brightly lit and viewed through the Chelsea colour filter, which transmits only deep red light and a narrow band in the yellow-green which in emerald is partly absorbed. The majority of emerald *imitations* absorb red light strongly and thus appear green through the filter, and so does heat-treated green tourmaline, which is not unlike emerald in appearance. Hence the appearance of a doubtful 'emerald' under the filter can be a useful guide. But this simple test must be used with great discretion, since there are many exceptions to the simple rule that red through the filter is a sign for genuine emerald and stones which remain green must necessarily be something other than emerald. In the first place, synthetic emeralds appear strongly red under the filter: in fact their ruby red colour is only matched by the very finest Colombian stones and furnishes a hint of danger. Then there are other natural green stones which assume a reddish tinge under the filter. Of these, green fluorspar from Pforte in South-West Africa has the

nearest approach to emerald in colour: the others, demantoid garnet and green zircon, would be unlikely to deceive any experienced jeweller. There are occasional soudé emeralds which also appear red under the filter. In the second place, there are some forms of emerald which still look green when viewed through the filter. These include emeralds from the Transvaal and those from the Udaipur district of India, in which there is enough iron to dim the red fluorescence and mar the free transmission of deep red light.

Another consequence of the presence of chromium in emerald is the absorption spectrum it displays, which is distinctive enough to enable the stone to be distinguished from any other gem species, and also serves to act as a guide where there is some doubt whether one is justified in calling a stone emerald or merely green beryl—since there are some green beryls which owe their colour mainly to iron. The absorption spectrum of emerald has been described and illustrated in Chapter 8. Having due regard to the appearance of the stone, the only other gem material which could possibly be confused with emerald on the basis of its absorption spectrum is fine translucent green jadeite, which also owes its colour to chromium and shows narrow chromium bands in the red having a general resemblance to those seen in emerald, but not nearly so clearly marked, and showing none of the variations due to dichroism which are a notable feature with emerald.

As for the other distinctive properties of emerald—the refractive indices and density vary perceptibly according to the locality where it was mined, owing to slight variations in chemical composition. Traces of iron and, more notably, the presence of the heavier alkali metals such as caesium, tend to raise the value of these constants. The inclusions, also, are usually distinctive for each locality, and the gemmologist will do well to familiarize himself with these things if he wishes to distinguish between natural emeralds and the **synthetic emeralds** made by Carroll Chatham in San Francisco, since these, being made by a slow process of crystallization, show none of the 'synthetic' features such as bubbles and curved lines of growth with which we are familiar in the Verneuil corundums, and we have to rely on a rather exact knowledge of constants and inclusions. The following table summarizes the constants of emeralds from the main localities and of synthetic emeralds.

Locality	R.I. (ord. ray)	Birefringence	Density
Synthetic	1·564	0·003	2·65
Brazil	1·571	0·005	2·69
Colombia, Chivor ...	1·577	0·006	2·69
Colombia, Muzo ...	1·584	0·006	2·71
Siberia	1·588	0·007	2·74
Habachtal	1·591	0·007	2·74
India	1·593	0·007	2·74
S. Africa	1·593	0·007	2·75

Of course there are slight variations within each locality, but the figures given may be found a useful guide.

Inclusions are not so easy to tabulate, but an indication of the most characteristic types can be briefly given. In Colombian stones, which probably constitute ninety per cent at least of fine emeralds used in jewellery, the most constant features are flat cavities with upper and lower margins jagged like a coarse saw, containing liquid, a bubble of gas and a little cube of rock-salt. Sometimes these three-phase inclusions may have only a single
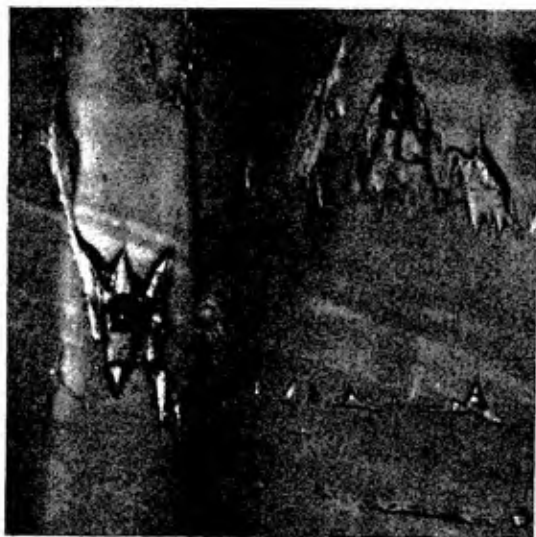
Figure 66. Three-phase inclusions in Colombian emerald

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'spike'. The cube of rock-salt is often elongated in one direction, giving it a rectangular outline, or it may be seen obliquely, in which case it presents a lozenge-shaped outline. These familiar inclusions are most commonly oriented parallel to the main axis of the original crystal. They are common to emeralds from both the Chivor and Muzo mines (see Figures 31 and 66). Distinctive for Chivor emeralds, when seen, are beautifully-formed little crystals of iron pyrites, recognizable by their metallic brassy lustre
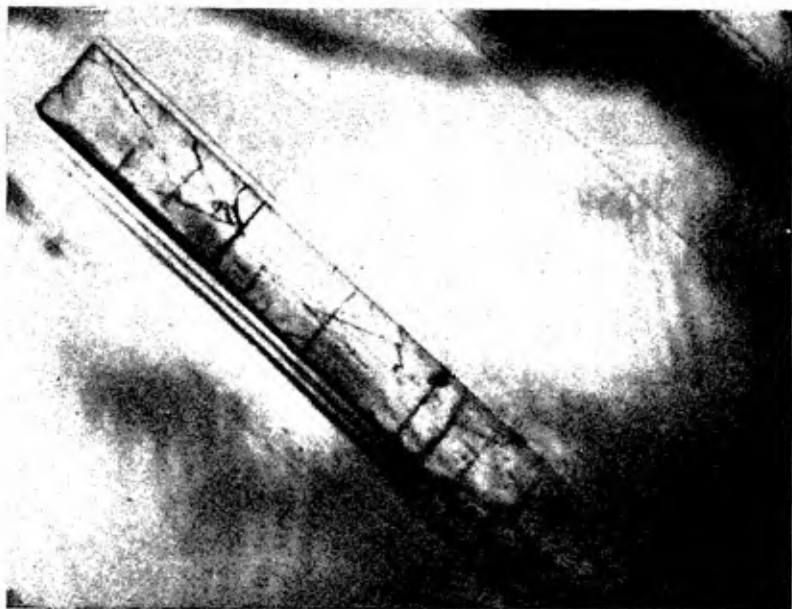
Figure 67. *Actinolite crystal in Siberian emerald*

and 'pyritohedral' form. Muzo stones, on the other hand, may reveal included rhombohedral crystals of calcite, and occasionally little pinkish inclusions of the rare-earth mineral parisite, which gives a strong rare-earth absorption spectrum. Emeralds from the Ural mountains (Siberian or Russian emeralds) have quite a different occurrence, and this is reflected in their inclusions. Flakes of mica may be seen, often broken or resorbed, but the most distinctive features are blades of green actinolite; cracks across the length of these gives them a 'bamboo shoot' appearance

(see Figure 67). Nothing resembling these green blades is seen in other emeralds, with the exception of the masses of actinolite or 'grammatite' fibres seen in some of the Habachtal stones. Another feature seen in Siberian emeralds is a development of thin, disk-like cavities parallel to the basal plane. These show a silvery lustre by reflected light, but in some directions may appear black, owing to total reflection. In Transvaal emeralds mica is usually a major inclusion, while in Indian emeralds are found

Figure 68. Negative crystals, containing liquid and bubble, in Indian emerald

hexagonal cavities ('negative crystals') parallel to the main axis of the crystal. In profile these have a rectangular outline, often with a small projection from one corner, and they enclose a small bubble of gas in a liquid—that is, they are two-phase inclusions. Mica is also often present (Figure 68).

As for **synthetic emeralds**, the most typical inclusions are lace-like feathers consisting of liquid-filled flattened canals forming intricate patterns. Nothing quite like them is found in any natural

emeralds. The photomicrographs shown in Chapter 6 will reveal their character better than any words. The only solid inclusions so far noted in Chatham emeralds are crystals of phenakite showing the typical habit of that beryllium silicate mineral.

A sensitive test for emerald, in which it differs from all stones of similar colour, is its red fluorescence between crossed filters—that is, when strongly illuminated with the blue light transmitted by a copper sulphate solution and viewed through a good red filter. Under these conditions, synthetic emerald shows a strong red glow, Colombian and Siberian stones also show a marked fluorescence, while stones from South Africa and India give a dimmer red effect.

Of natural stones which resemble emerald in appearance, there are only three which deserve serious mention. One is the emerald-green **fluorspar** from South-West Africa (and presumably from other localities, since material of this kind is sometimes met with in carved Chinese images and objets d'art). This has been mentioned briefly already as showing a reddish residual colour under the Chelsea filter. A further similarity between green fluorspar and emerald may sometimes be noted under the microscope, since three-phase inclusions with gas bubble and cube of rock-salt may be found in green fluorspar, resembling rather closely the well-known inclusions in Colombian emerald. Other tests, however, make distinction between the two an easy matter for the gemmologist. On the refractometer, for instance, fluorspar gives a single shadow-edge at the low figure of 1·434, and, being singly refracting, fluorspar has no dichroism. With loose stones, the higher density of fluorspar (3·18) is quickly revealed by a trial in bromoform, in which it sinks decisively, whereas emerald rises to the surface with equal alacrity. Also, under ultra-violet rays (3650 Å), the fluorspar displays a violet fluorescence. Fluorspar ranks as the standard 4 on Mohs' scale of hardness, against emerald's 7½—and this, together with its low refractivity, gives it a far lower lustre than beryl.

The second natural stone to be mentioned for its colour-resemblance to emerald is a variety of **tourmaline** which also, by a curious chance, comes from South-West Africa. As found, it is a deep blue-green in colour, but by suitable heat-treatment it assumes a paler and purer green shade, not far removed from that of emerald, and the strong dichroism of the untreated tourmaline

is no longer noticeable. Here again the refractometer provides the surest single test, since the values of 1·620 and 1·638 given by tourmaline are completely distinctive. The expert eye is in any case unlikely to be deceived in this instance, as the colour of the tourmaline is definitely not quite 'right' for emerald.

The third stone which might on occasion be confused with emerald is **jadeite**, which also owes its colour to chromium, and occasionally achieves an almost emerald green. Jadeite is never transparent, however, so that the confusion would only arise between this and emerald of a quality hardly suitable for use in jewellery. The slight similarity between the absorption spectra of the two species has already been mentioned earlier in this chapter. The appearance under the microscope and the higher refractive index of jadeite (with cabochon stones the 'distant vision' method can be used) will help to remove any doubts. Another distinctive feature of jadeite which may be mentioned is its slightly dimpled or shagreened surface when polished, due to slight local differences in hardness.

Other natural green stones need hardly be mentioned in this connection. **Demantoid garnets** often contain traces of chromium and then have a fine colour—more yellowish green, however, than with emerald. The brilliant lustre and 'fire' of demantoid in themselves are distinctive—as also its 'horsetail' fibrous inclusions, single refraction, and absorption spectrum. **Green sapphire** and **green zircon** need hardly be mentioned as serious rivals to emerald, though their properties are included in the comparative table given below for completeness' sake. The same can be said for **peridot**, which has a distinctive yellowish-green colour of its own.

Turning now to the **imitations** of emerald. These may be either composite stones or some form of emerald-green glass, and can be very deceptive to the eye, especially when set in jewellery. Dealing first with composite stones: though such things may exist, the author has never yet encountered a *true* **emerald doublet**—that is, one consisting of two shallow pieces of emerald cemented together to form a more important whole. The cheap doublet with thin garnet top fused to a green glass base is sometimes seen, but the most successful imitation is the so-called '**soudé emerald**' made from a thin slice of emerald-green glass sandwiched between two thicker pieces of quartz, the quartz being specially chosen for

its natural emerald-like feathers. In soudé emeralds the quartz-glass junctions usually occur at or near the girdle, and may thus be concealed in a set stone. The quartz provides a material with density, refractive index, and hardness only slightly below that of emerald, but on a refractometer there should be no doubt at all in the observer's mind, since quartz gives readings (1·544–1·553) quite distinctly lower than emerald, and in sodium light the bire-fringence is noticeably larger. Free from its setting, soudé emerald, in common with all other triplets, can of course be easily detected by viewing the composite stone sideways in a vessel of liquid, when

Table for Identifying Green Stones

Species	H.	S.G.	R.I.	D.R.
Emerald ...	$7\frac{1}{2}$	2·71	1·57–1·58	0·006
Zircon... ...	$6\frac{1}{2}$	4·0[1]	1·82*	0·01*
Sapphire ...	9	4·00	1·76–1·77	0·009
Demantoid ...	$6\frac{1}{2}$	3·85	1·89	none
Peridot ...	$6\frac{1}{2}$	3·34	1·65–1·69	0·037
Jadeite ...	7	3·33	1·65–1·67	0·014
Fluorspar ...	4	3·18	1·43	none
Tourmaline ...	7	3·05	1·62–1·64	0·018
Beryl glass ...	7	2·49	1·52	none

* The constants for green zircon are very variable.

the component parts can be clearly distinguished. If a density test be applied, the soudé triplet often shows surprisingly high values (an actual example being 2·88) considering that the bulk of the specimen consists of quartz (S.G. = 2·65). This indicates that a very heavy lead glass is used for the middle layer. In a less usual form of 'soudé' the coloured layer consists of gelatine stained with an emerald-green dye-stuff. This layer is apt to 'go bad', and then presents an unpleasant yellowish blotchy appearance. Owing to the dye-stuff used, this form of triplet is apt to show red under the Chelsea filter. Thus a test with the refractometer, spectroscope or microscope should always be carried out where possible.

Recently, 'soudé emeralds' in which the upper and lower por-tions consist of colourless synthetic spinel have been marketed.

The lack of a red reaction under the Chelsea filter or of any dichroism are warning signs, and a refractometer reading of 1·727 will complete the revelation of this fraud. There is also a highly suspicious lack of inclusions.

One interesting type of **glass imitation** which is occasionally used to simulate emerald is actually composed of fused beryl coloured with chromic oxide, thus having the chemical composition, though not the crystal structure, of emerald. Such specimens may form very good imitations so far as colour is concerned, and are harder than the normal run of glasses. The refractive index (near 1·52) and density (near 2·42) are, however, very much lower than for crystallized beryl, and included bubbles are always to be seen. The more ordinary **'paste' imitations** of emerald usually consist of rather soft lead glasses having refractive indices between 1·60 and 1·66 and densities between 3·40 and 4·00, though calcium glasses having much lower constants are sometimes used. Films and chains of bubbles in imitation stones serve to give a deceptively natural 'mossy' look to the specimen, though closer inspection with a lens will, of course, reveal the fraud.

In conclusion, it should be mentioned that **synthetic corundum** and **synthetic spinel** are both manufactured in various shades of green. True emerald green, however, has not been achieved in these materials.

AQUAMARINE AND ALEXANDRITE

THE beautiful sea-green or sea-blue beryl so appropriately known as aquamarine is one of the most popular amongst the gemstones, and a few notes on its identification may be useful to the jeweller. So far as colour goes, there are only two natural species which closely resemble aquamarine—**blue zircon** and **blue topaz**.

The former of these can easily be recognized by its 'fire', lustre, and strong double refraction, but topaz, in the rare cases when it it is found with a distinctly blue tint, can hardly be distinguished from aquamarine by eye alone. In addition to these two natural minerals, there are artificial substitutes which are likely to cause trouble. These include **glass imitations** of various types, **synthetic blue spinel** similar to that used in simulating zircon, and, possibly, **doublets**.

The trained eye can usually 'spot' a synthetic spinel at sight: the blue is a little too gaudy and the lustre and fire are a little too bright to belong to a beryl, in which the lustre is decidedly glassy, and the dispersion low. Without the use of instruments, **glass imitations** are often difficult to identify. Under a lens, glistening spherical bubbles may be sometimes detected, and when seen provide conclusive evidence that the specimen is a glass, since no natural mineral shows bubbles of this kind, and in synthetic spinel any bubbles will be 'profilated' or of so small a size that a microscope is needed to recognize them for what they are.

Glass being a bad conductor of heat, these imitations will feel warm to the touch compared with a genuine aquamarine. The stone should be cleaned, allowed to attain room temperature, then gently touched with the tip of the tongue, using tongs to hold the stone (unless it is mounted in jewellery). A similar test carried out on a piece of rock-crystal and a piece of ordinary glass will provide a helpful comparison. It is said (we hope untruly) that the jeweller still sometimes reaches for a file when testing for a paste—but not only are some 'aquamarine' glasses very hard, but also it should be realized that even a piece of paste jewellery may be valued by its owner, who may not welcome its return with a large file-mark across it!

Synthetic spinel, apart from its too-handsome appearance, can be separated from aquamarine at once by holding the stone under a good light and looking at it through a Chelsea colour filter. The blue synthetic will show a bright orange or red, while aquamarine appears a very distinct green, since it cuts out the deep red very effectively. Synthetic blue spinels which contain no cobalt have been made, and these do not show red through the filter. Stones of this type, however, are practically never seen in jewellery.

Doublets made to simulate aquamarine are hardly ever met with, but the possibility of a doublet should always be borne in mind by the careful jeweller when examining any gemstone.

From what is written above, it should be clear that only the following are likely to be confused with aquamarine: zircon, topaz, synthetic spinel, and glass imitations, all of the appropriate colour. Of these, examination with a lens will eliminate zircon (strong double refraction) and many glasses (bubbles), while the Chelsea filter will detect synthetic blue spinel. If these positive signs are lacking, however, we are still left in doubt as to whether our stone is indeed an aquamarine, a blue topaz, or some form of glass imitation free from obvious bubbles. Once more, the scientific tests recommended and described in this book make it possible quickly to arrive at a definite decision.

First, let us turn to the refractometer. Aquamarine will give a reading near 1·58, with the small double refraction of 0·006. Any stone giving readings below 1·56 or above 1·60 can be definitely rejected as not true aquamarine. The reading for topaz is decidedly higher (1·62), with D.R. 0·01, while the majority of glass imitations have their single refractive index in the 1·50 to 1·51 region or are lead glasses with R.I. near 1·64. It must be admitted, however, that there are some glasses in which both R.I. and density are nearly the same as for beryl. Using sodium light, or a spinel refractometer, the distinction would of course be simple, since aquamarine would then show its distinctive double-refraction, impossible in a glass; but the double refraction is too small to be seen in white light on a standard refractometer, and thus, should a reading near 1·58 be obtained, it will still be wise to examine the stone under the microscope, or with a dichroscope, to confirm that it is a genuine stone.

The dichroscope, perhaps, provides the simpler test, and can

easily be applied to a stone even when in a setting, providing that it has an open back so that light can pass through it. Aquamarine is decidedly dichroic; with a green specimen, one image in the dichroscope will appear a deeper green than the specimen as a whole, while the other image will be practically colourless; with a blue specimen one image will again be colourless, and the other a pronounced blue. With Madagascan stones in particular this blue image is a magnificent colour; unfortunately (a note for the
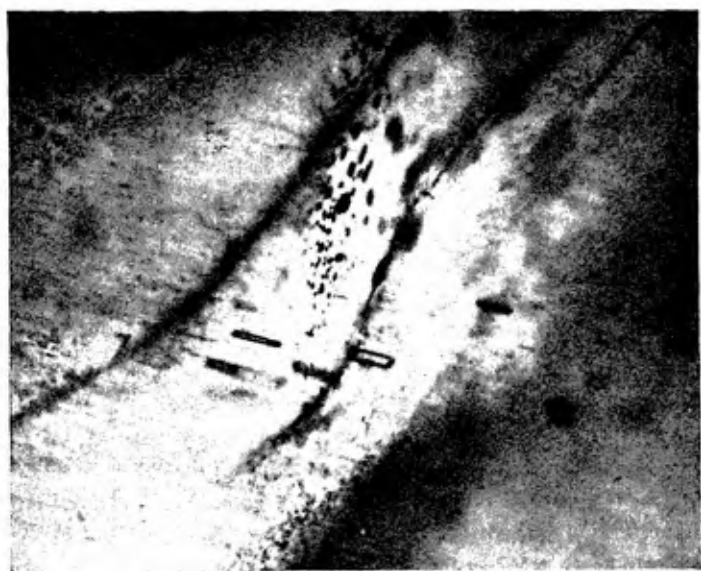
Figure 69. Inclusions in aquamarine. 'Rain' and two-phase inclusions parallel to main axis and layers of disks at right-angles to these

interest of advanced readers) the blue colour belongs to the 'extraordinary' ray, and thus, however the stone be cut, it is always diluted with the colourless 'ordinary' ray when viewed with the naked eye.

In testing for dichroism, one must remember to view the stone from several angles to ensure seeing the full effect. Also, it is better to use light reflected from a white wall or cloud, as a sunlit sky is in itself slightly dichroic, and may lead the observer to credit this slight effect to the specimen.

The microscope, which is always invaluable when it comes to distinguishing natural and artificial gems by its revelation of their internal features, can also be used to help us here. Glass imitations will usually show a bubble or two, even if these be too small to be detected with a pocket lens—or they may show 'swirl marks' as a result of improper mixing of the constituents. Aquamarine on the other hand, being a natural mineral, will commonly show layers

Table for Identifying Aquamarine

Species	H.	S.G.	R.I.	D.R.
Aquamarine ...	$7\frac{1}{2}$	2·70	1·574–1·580	0·006
Zircon... ...	$7\frac{1}{2}$	4·69	1·926–1·985	0·059
Synthetic spinel	8	3·63	1·727	none
Topaz	8	3·56	1·610–1·620	0·010
'Mass aqua' ...	6	2·37	1·50	none
Beryl glass ...	$6\frac{1}{2}$	2·44	1·52	none

Lead glass imitations may vary from S.G. 2·63, R.I. 1·57 to S.G. 3·85, R.I. 1·64 or higher. Their hardness is only about 5 on Mohs' scale.

of small crystals ('feathers') or thin, needle-like crystal inclusions, or thin tubes containing liquid and perhaps a bubble of gas. These lie parallel to the main (hexagonal) axis of the original crystal (see Figure 69).

If no refractometer is available, and the stone can be obtained free from its setting, it may be tested in a heavy liquid. Here one can separate topaz, zircon, synthetic spinel, or the heavier pastes from aquamarine simply by immersing the stone or stones in pure bromoform (2·9) or methylene iodide (3·3); aquamarine floats while the others sink. Any pale blue specimen, in fact, which floats in these liquids and is also dichroic, can be accepted as genuine aquamarine. Even without such aids, dealers accustomed to handling aquamarines can usually detect the intrusion of a blue topaz when weighing these stones individually, since a topaz of this colour is more than 30 per cent heavier than an aquamarine of the same size.

Stating the matter as briefly as possible, one may say that the

only single test which will in itself provide a positive determination of aquamarine is a careful refractometer reading in sodium light (or with a spinel refractometer in ordinary light) when not only the mean index but also the double refraction can be measured. Failing this, either a rough refractometer reading or a density test may be made, combined with a dichroscope observation.

Before concluding, it may be well to state here that *there are no synthetic aquamarines on the market*. Specimens so called will either be synthetic blue spinels or pastes. A glass made from fused beryl, and thus having the same *chemical composition* as aquamarine, is indeed sometimes seen, but, not being crystalline, its properties are quite different from those of beryl, as can be seen from the table above, in which the physical constants of all the stones and imitations discussed in this chapter are given in a form suitable for reference. 'Mass aqua' is the popular name for a special hard glass imitation of aquamarine; the constants for a typical specimen are given.

ALEXANDRITE

Alexandrite is a variety of the mineral *chrysoberyl*, which also provides stones of a clear greenish yellow, of a brown colour not unlike tourmaline, and honey-coloured cat's-eyes showing a narrow silky ray when cut *en cabochon*.

Although alexandrite has not much intrinsic beauty, the curious change in colour from dull green in daylight to raspberry red in artificial light has its attraction, and this, combined with the rarity of good specimens, places it amongst the more costly gemstones.

So far as appearance goes, no natural gemstone is likely to be confused with alexandrite, except perhaps the equally rare **andalusite**, which has reddish gleams mingled with the green body-colour of the stone, owing to its strong dichroism. So-called 'synthetic alexandrites', however, are often met with, which are generally **synthetic corundum**, but sometimes may be **synthetic spinel.**

There is no such thing as synthetic alexandrite or synthetic chrysoberyl of any kind on the market. The corundum synthetics intended to simulate alexandrite can be recognized at sight by an experienced person; they have not the dull green of alexandrite in daylight, but are either purplish or a peculiar shade of slaty blue. In artificial light they are a quite handsome red—*too* handsome, in fact.

Alexandrite-coloured synthetic spinels are seldom seen, but so far as appearance goes they are more convincing than the corundum counterfeits.

There are several simple tests which can be made to distinguish true alexandrite with certainty from these two synthetics.

Firstly, since they belong to a different mineral species, with different properties (see table below) they can be quickly distinguished on the refractometer.

The R.I. of alexandrite being not far below corundum, a careful reading is needed for a decisive distinction between the two

Identification of Alexandrite

Species	H.	S.G.	R.I.	Dichroism
Chrysoberyl (alexandrite) ...	8½	3·71	1·745–1·754	strong
Synthetic corundum ...	9	3·99	1·761–1·770	strong
Synthetic spinel ...	8	3·63	1·727	none
Andalusite	7½	3·15	1·635–1·645	strong

minerals; but the synthetic spinels are very easily distinguished by their decidedly lower, and single, refraction.

A specific gravity test will also serve to distinguish the three minerals, using Clerici solution. Under the microscope, the synthetic corundums will reveal the usual spherical bubbles; if these are hard to find, the curved structure lines are invariably present, and can be seen clearly if the stone is viewed from the correct angle. The spinel imitations may not show bubbles, but the lack of double refraction will be evident under the microscope by the failure to show any doubling of the back facet edges when viewed in sharp focus through the front of the stone, while between crossed Polaroids it will show a typical 'tabby extinction' effect.

Finally, the appearance through the dichroscope and spectroscope of light transmitted by genuine alexandrite is distinctive, especially with the latter instrument. Careful observation from different angles with the dichroscope will reveal three differently coloured rays in alexandrite: green, purple, and orange—though

of course only two of these can be seen together at any one time in the two adjacent images visible through the eyepiece of the dichroscope. The corundum counterfeit shows brownish and mauve while the spinel, being singly refracting, has no dichroism at all.

Alexandrite owes its peculiar balance of colour between red and green to its absorption spectrum, and this in turn is due to the presence of small amounts of chromic oxide in this variety of chrysoberyl. The spectrum may be recognized by the two strong dark lines very closely together (known as a 'doublet') in the deep red, two weaker lines in the orange-red, and a broad absorption band covering the yellow and some of the green. Synthetic 'alexandritic' corundum owes its colour partly to vanadium, and has none of the above characteristics, but a tell-tale narrow absorption band in the blue, which proclaims it at once for the fraud it is. The spinel counterfeits may show a vague cobalt spectrum with three broad bands in the orange, yellow, and green respectively.

All in all, a careful refractometer reading is the best test for alexandrite. If the reading is different by more than a few integers in the third place of decimals from the average figures 1·745 and 1·754 for the lower and upper shadow-edges, the stone is not an alexandrite chrysoberyl.

Siberian alexandrites show the most decided colour change, while those from Ceylon, though inferior in this respect, are obtainable in larger and more flawless pieces. In a case where there is so little colour-change that it is doubtful whether one should term the stone chrysoberyl, or whether one is ethically entitled to use the better selling name of alexandrite, the spectroscope can be called in as arbiter. If the chromium lines in the red can be seen distinctly, the stone has a right to the title 'alexandrite'.

Alexandrite also shows a red fluorescence between crossed filters, that is, when a powerful beam of light is directed on to the stone through a copper sulphate solution, which is then viewed through a good red filter. Any chrysoberyl not showing this fluorescence under such conditions cannot be classed as alexandrite. Laboratories are sometimes faced with such distinctions, as the name 'alexandrite' has a powerful sales attraction, while plain 'chrysoberyl' means little to the average jeweller or to the public.

The properties of alexandrite, andalusite and the synthetic counterfeits are tabulated above, for reference.

IDENTIFICATION OF ZIRCON

SINCE the day, some forty years ago, when the first Siamese blue zircons appeared on the market, this attractive gemstone has gained steadily in popularity, and now may figure as prominently in the jeweller's window as such old favourites as aquamarine, amethyst, or topaz.

Before the influx of these heat-treated types from Bangkok, Ceylon was practically the sole source of gem zircon, which is very common in the gravels of that island. The term 'zircon' itself was hardly known outside scientific circles, the name 'jargoon' being commonly used in the trade. Even in those days the superficial similarity between well cut colourless zircon and diamond was realized, and the misleading sobriquet 'Matura diamond' or 'Matara diamond' from Matara in Ceylon was carelessly or craftily applied to such stones.

In the writer's experience, no stone, apart from opal and diamond, can so readily be identified at sight, or with the aid of a simple pocket lens, as zircon. Recognition at first glance is often possible on account of its peculiar lustre, part adamantine, due to its high refractivity, part greasy or resinous, due to some peculiarity in its reaction to the polishing process. There is also often a characteristic milkiness and a 'fuzzy' out-of-focus appearance, which is caused by the strong double refraction referred to later.

Colour is also a considerable guide. No other natural stone produces such splendid sky-blue specimens, no natural colourless stone so near an approach to the 'fire' of diamond; and the red, yellow, and brown types are usually sufficiently different in appearance from other minerals of similar colour. Green zircons alone are liable to be misleading; they have little or no double refraction and lower refractive index than the normal types; moreover, the lustre does not appear so distinctive. If one becomes familiar with the peculiar shade of zircon green one may usually distinguish it from green sapphire, demantoid garnet, or a deep green peridot, which most closely approach it. Though often too dark, or too milky or sleepy, to be attractive, green zircon can occasionally be an exceedingly beautiful stone.

Zircons are very brittle on the surface, especially those which have been subjected to heat treatment—and this includes practically all modern zircons—which provides another means of recognition in the chipped and rubbed appearance of the edges and corners of a faceted stone if it has been worn for some time, or even packeted with other zircons.

Examination with a pocket lens usually provides convincing evidence of the identity of a zircon, since the strong double refraction makes very obvious the apparent doubling of the edges of the back facets as seen through the table. To illustrate this effect, a photomicrograph (Figure 70) was taken through the table facet of a small brilliant-cut zircon, which plainly shows the doubled images of the culet and pavilion edges, and, incidentally, the chipped and rubbed condition of these edges which is also typical, as mentioned above.

In cases where the so-called 'optic axis' of the stone (i.e., the unique direction of single refraction) is at right-angles to the table facet, it may be necessary to tilt the specimen to see the doubling effect clearly. This very useful method of observation has already been discussed in Chapters 3 and 9, but it is of such practical value, not only for zircon but for many other stones, in detecting and roughly gauging the amount of double refraction, that no apology is made for stressing it again here. If every jeweller and pawnbroker would practise this test, there would be no danger of the confusion between white zircon and diamond that is quite frequently made.

The only natural gemstone liable to be confused with zircon is **sphene**, which also has high refractive indices, strong double refraction, and high dispersion. Sphene is something of a rarity, and quite good prices are paid for fine specimens by collectors, so that it is worth while keeping an eye open for this attractive gemstone. Its low hardness ($5\frac{1}{2}$), however, debars it from general use in jewellery. Sphene is invariably either yellow, green, or brown, so that when dealing with white or blue zircons this possibility may be discounted.

Sphene differs from zircon in showing quite strong dichroism, while in zircon of similar colour this phenomenon is virtually absent. The density of sphene (3·53) is also far lower than that of zircon, which provides an easy means of distinction with unmounted specimens. The spectroscope provides another rapid

test for distinguishing zircon from all other gems, as mentioned below.

Cassiterite is very rarely transparent enough to be worth cutting as a gem, and is usually very dark brown in colour. But, having a high refractive index and strong double refraction, it is occasionally possible to confuse it with zircon. Its dichroism, the lack of the zircon spectrum, and (in unmounted specimens) its outstandingly high density (near 7·0) are amongst the most useful
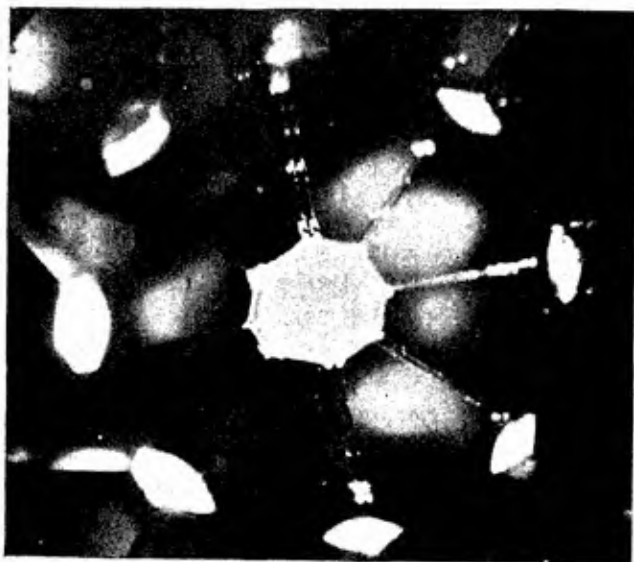
Figure 70. Double refraction seen through table facet of zircon. Magnified 18 diameters

distinguishing features. The enormous double refraction and 'fire' of **synthetic rutile** give it an appearance all its own, so that tests are hardly necessary: but the beginner should bear it in mind, and not assume that all off-white stones showing strong 'doubling' of the back facets need be zircon.

Normal zircon, with its high refractive indices of 1·926 and 1·985, is beyond the range of the ordinary refractometer, and will thus give what is called a 'negative' reading—i.e., the shadow will extend to the edge due to the contact liquid used.

Zircon shares this effect with diamond, sphene, and demantoid, but this negative reading will at least distinguish it from synthetic

spinel and other remoter possibilities. One other test for zircon which is rapid and certain is open to the jeweller who possesses a small prism spectroscope and the skill to use it. All the heat-treated blue or white zircons used in jewellery show, though often very faintly, a narrow absorption band in the orange-red of the spectrum of light passed through it, which is not shown by any other stone. Usually a neighbouring, even fainter, band may be seen and, more rarely, other narrow bands in other parts of the spectrum. Always, however, the strongest and most persistent band is the one in the orange-red (actual measurement, 6535 Å). By this means the author has often checked parcels of zircons more quickly than could have been done by other tests, and quite as surely. Details of the technique involved will be found in Chapter 8.

Yellow, golden brown, and greenish stones from Ceylon, which at one time were the only zircons used in jewellery, show a much stronger and more complete spectrum. In these, the 6535 Å band is still the most powerful, but a series of other lines are seen at almost equal intervals throughout the spectrum, seven of them being quite strong and four or five of them rather weak. It was this striking spectrum which delighted the eye of the famous Victorian gemmologist Sir Arthur Church when he first discovered the phenomenon in 1866. The greenish-brown zircons from Burma display an even richer spectrum, numerous fainter lines making their appearance between the strong ones already mentioned. For a more complete account of the zircon spectrum the reader is referred to Chapter 8.

The only stones deliberately intended to counterfeit zircon are **synthetic spinels** coloured in various shades of blue by the presence of cobalt. These are attractive, bright stones, and the colour is often very near to that of blue zircon. There is comparatively little fire, however, and of course no sign of double refraction, so that careful inspection alone should remove all doubt. Moreover, under the Chelsea colour-filter, the blue synthetics appear red or orange, whilst blue zircon assumes a dull greenish tint. In addition, the refractometer will give a reading near 1·727 for synthetic spinel, and its density (3·63) is also far below that of zircon. Thus the distinction could hardly be more easy.

The reader may have noticed that reference has been made several times to 'normal' zircon. This is because there are certain

abnormal zircons from Ceylon with different density, refractive index, and double refraction from the normal type. Since practically all the zircons now used in the trade belong to this normal category the existence of the other types need seldom worry the jeweller, and indeed it is only *green* zircons in which the properties are sufficiently distinct from the ordinary to be somewhat puzzling to those not forewarned. These may have practically no double refraction and a density as low as 3·96 with R.I. 1·79, observable on the refractometer, though usually these figures are somewhat higher.

For more than fifty years, the extraordinary variations in the properties of Ceylon zircons formed one of the mysteries of mineralogy, and formed the subject of numerous papers. The mystery was finally solved in 1936, when Chudoba and Stackelburg, using the methods of X-ray crystal analysis, established that in Ceylon zircons there is a gradual breakdown of the crystal lattice due to internal bombardment by alpha-particles shot out by the uranium atoms present in the stones. In the lowest types, only a mixture of amorphous oxides of zirconium and silicon remains. After long heating at a high temperature, all 'low' and 'intermediate' zircons tend to revert to the normal fully crystalline state, their density, refractive index and birefringence increasing accordingly.

In the green zircons the absorption spectrum usually shows a woolly band in place of the clearly defined narrow band in the orange-red of high zircon. An occasional 'low' zircon may show quite a strong spectrum, in which there are three bands in the red in place of the usual 6535 Å band. In yet another type of green zircon, which is singly refracting with an index near 1·82, a woolly band in the red is accompanied by a clearly defined narrow band in the green at 5200 Å.

Dichroism in zircon is very weak in all colours except the heat-treated blue variety. In this, curiously enough, the effect is quite strong, the twin colours being blue and almost colourless.

It should perhaps be mentioned that blue zircon has an unfortunate tendency to 'revert' in colour to its original reddish-brown tint. Such reversion is particularly apt to happen when the stone has been exposed to bright sunlight or to any other strong light which is rich in ultra-violet rays. The change is seldom complete, but, at its worst, brownish blotches appear, which completely ruins the beauty and value of the stone. The pleasing blue tint can

often be restored to such stones by careful heating to redness. It is risky to do this in an open Bunsen flame or alcohol lamp, as sudden heating or cooling may produce cracks. A safer method is to bury the stone in powdered charcoal, contained in a small crucible, and to heat this to bright red heat (800–900° C) for about two hours, then allowing it to cool gradually. Carbon monoxide from the charcoal ensures a 'reducing' atmosphere, which has been found favourable for the production or restoration of a blue tint in zircon. Colourless zircons also tend to discolour, and these can usually be restored by careful heating: the author has done this successfully on the hot-plate of an Aga cooking stove. The golden-yellow stones from Indo-China, though also the product of heat treatment, seem to be quite stable as to colour.

In concluding this chapter, one may summarize the simplest methods for distinguishing zircon from other gemstones, as follows. If the specimen is colourless or pale blue or greenish-blue in colour and strong doubling of the back facets can be seen with a pocket lens, the stone is undoubtedly zircon. If the stone is yellow or greenish yellow and shows strong doubling, it *may* be a sphene, which is worth far more than zircon. The dichroism of sphene, the absorption spectrum of zircon, or (with loose stones) a density test, will quickly settle the issue. The yellowish synthetic rutile has a double refraction and fire far beyond those seen in zircon, but should be borne in mind by beginners.

Peridot also shows quite strong double refraction under a lens, but has a characteristic shade of green, unmatched by zircon, and its absorption spectrum and other properties are completely different. Far more likely to be confused with zircon is the mineral **sinhalite**, which for years was thought to be a golden-brown or yellow variety of peridot, but has recently been established as a completely new species by G. F. Claringbull and M. H. Hey. The greenish-golden colour most typical of sinhalite can match very closely a common form of Ceylon zircon, and the author has on several occasions rescued sinhalites from 'zircon' packets. Sinhalite shows 'doubling' to the same degree as peridot, that is, not quite so strongly as zircon. The best test for this interesting gemstone is on the refractometer, since its indices of 1·670–1·706 (with slight variations according to colour) are quite distinctive. Sinhalite has an absorption spectrum very similar to that of peridot, except for an extra band at 4630 Å.

As for stones which do *not* show double refraction, but which resemble zircon to some degree in colour and appearance, synthetic blue spinel has already been mentioned as the only deliberately manufactured substitute for blue zircon. Its orange appearance under the Chelsea filter, cobalt absorption spectrum, single refractometer reading at 1·727, and anomalous double refraction (tabby extinction) between crossed Polaroids, are some of the easy tests which serve to identify this synthetic. Deep red zircon is occasionally confused with almandine garnet, which may also give a shadow-edge right up to the edge at 1·81 due to the contact liquid on the refractometer. The distinctive absorption spectrum of almandine, however, always provides an easy test. Green zircon may be singly refractive, or virtually so, and may be confused with the green garnet, demantoid, by those unfamiliar with their different appearance. The 'horsetail' inclusions of demantoid and its absorption spectrum provide rapid means for its identification.

In the appended table, the properties of all stones likely to be confused with zircon are summarized, while some values for individual zircons, measured by the author and C. J. Payne, are also

Identification of Zircon

Species	H.	S.G.	R.I.	D.R.	Dichroism
Normal zircon ...	7½	4·69	1·93–1·99	0·059	weak (blue strong)
Cassiterite ...	6½	6·90	2·00–2·10	0·096	distinct
Synthetic rutile...	6	4·25	2·61–2·90	0·29	very weak
Almandine ...	7½	4·20*	1·81*	none	none
Low zircon ...	6½	3·96†	1·79†	none	very weak
Sapphire (green)	9	4·00	1·76–1·77	0·008	distinct
Demantoid ...	6½	3·85	1·89	none	none
Synthetic spinel...	8	3·63	1·727	none	none
Topaz (white) ...	8	3·56	1·61–1·62	0·01	none
Sphene	5	3·53	1·90–2·02	0·12	distinct
Diamond ...	10	3·52	2·42	none	none
Sinhalite... ...	6½	3·48	1·67–1·71	0·038	distinct
Peridot	6½	3·34	1·65–1·69	0·036	weak
Tourmaline ...	7	3·06	1·62–1·64	0·018	strong

* Maximum figures.   † Minimum figures.

tabulated, to give the reader an idea of the range shown by this interesting gemstone.

Properties of Individual Zircons

Specimen	S.G.	R.I.	D.R.
Golden brown ...	4·711	1·933–1·992	0·0588
Golden, Indo-China ...	4·697	1·926–1·985	0·0594
Brown, Burma ...	4·693	1·926–1·984	0·0580
Colourless, Ceylon ...	4·687	1·926–1·985	0·0590
Yellow-brown, Ceylon	4·61	1·922–1·972	0·050
Yellow-green, Ceylon	4·43	1·900–1·925	0·025
Green, Ceylon ...	4·185	1·865–1·875	0·010
Green, Ceylon ...	4·12	1·832–1·849	0·017
Green, Ceylon ...	3·99	1·830 —	—
Green, Ceylon ...	3·965	1·792–1·796	0·004

It will be noted that the 'low' zircons are all green, and all from Ceylon. The last specimen on the list was loaned to Prof. Chudoba, and used by him in establishing the reason for the strange variation in properties of zircon, in the research already mentioned.

IDENTIFICATION OF TOPAZ

In times past, the name of 'topaz' has been applied, with different prefixes, to yellow stones of several entirely distinct species. Thus 'oriental topaz' denoted yellow corundum; 'occidental topaz', 'Spanish topaz', etc., were names for yellow quartz, while the prefix 'Brazilian' distinguished the gemstone to which the name topaz can alone be rightfully applied today. For the persistent incorrect use of the term topaz (with or without some fancy prefix) for various shades of yellow or brownish-yellow quartz the influence of big dealers in the German stone-cutting centre of Idar-Oberstein was perhaps largely to blame. Their trade in gems of the quartz family was far and away greater than for other stones (including true topaz), and they clung obstinately to 'topaz' as a good selling name for quartz of topaz hue.

Importers in this and other countries, receiving parcels from Idar labelled 'topaz' would naturally sell the stones under this name—and so the misnomer persisted, and still persists. Some of the most heated discussions in the Precious Stone Committees at pre-war B.I.B.O.A. (International Jewellery Trades Bureau) conferences have centred round the misuse of this particular name, and various unsatisfactory compromises have been suggested.

It is to be hoped that those jewellers and dealers who are well enough educated in their trade to understand the difference between true topaz and quartz will take the lead in describing yellow quartz correctly—either as 'citrine' or as 'golden quartz', reserving the term 'topaz' strictly for veritable specimens of that much rarer mineral species. For brown quartz the name 'cairngorm' can be used with perfect propriety, if so desired.

Let us now turn to a consideration of the characters of topaz itself. In nature this mineral is most often colourless, though frequently found in shades of yellow, and less commonly of blue and pale green. Certain sherry-coloured types from Brazil, when carefully heated, assume an attractive shade of pink, and it is these heat-treated stones which provide the majority of the pink specimens on the market. Topaz is one of the hardest of gems, being the standard 8 on Mohs' scale.

The refractive index and density vary slightly, and in opposite senses, for yellow and pink stones on the one hand and white and blue on the other, owing to the presence of more fluorine and less hydroxyl in the latter. Yellow and pink stones have R.I. 1·63–1·64, D.R. 0·008, and S.G. 3·53, while for colourless and blue stones the corresponding figures are 1·61–1·62, 0·010, and 3·56. Dichroism is distinct in the pink stones, less strong in the yellow. Topaz takes an exceptionally high polish, and some have claimed that a cut topaz can be recognized by its characteristically slippery feel. The great Victorian gemmologist, Sir Arthur Church, relates in his privately printed Memoirs how he was able to extract the topazes from a mixed bag of stones offered at half-a-crown apiece in a junk-shop, by inserting his hand into the bag and applying 'the inner aspect of a well-educated thumb' to the stones.

As for the stones which may be confused with topaz, undoubtedly the **yellow quartz** so commonly sold as 'topaz', as mentioned above, is the most likely substitute. Relying on appearance alone, it must be admitted that the two can often not be distinguished with any certainty, though the colour of topaz is usually richer and more subtle than that of quartz and it takes a higher polish. To emphasize how entirely different in every respect except appearance these two minerals are, let the reader glance at the characters of each:

	Composition	System	H.	S.G.	R.I.
Topaz	$Al_2(F,OH)_2SiO_4$	rhombic	8	3·53	1·630–1·638
Quartz	SiO_2	hexagonal	7	2·65	1·544–1·553

If the stone is unset, the considerably higher density of topaz may be perceptible when the stone is balanced in the hand; it is far more satisfactory, however, to make really certain by slipping the stone into either bromoform or methylene iodide, when topaz will sink whereas quartz will float. Quartz indeed has so constant a density, whatever its colour, that it is worth while to keep a bromoform solution diluted with benzene, toluene, or bromonaphthalene to an exact density of 2·65, controlled by the suspension of a specimen of rock-crystal quartz as an indicator. Then amethyst, colourless, or yellow quartz can all be identified with virtually complete certainty in the liquid, as they too will remain suspended or rise or fall very slowly, as the indicator does. Incidentally, such a liquid will also serve to distinguish between quartz

and chrysoberyl cat's-eyes and in the identification of synthetic emerald.

Should it be desired to test the stone in its setting, the refractometer, as usual, provides the most satisfactory, or rather, the *only* satisfactory means, and will also serve to separate topaz from other stones or counterfeits of similar appearance. Apart from quartz, these are most likely to be yellow specimens of **sapphire**, **tourmaline**, **beryl** and (less probably) **chrysoberyl** or **zircon**. Where pink topaz is in question, pink **tourmaline** or **corundum** have to be considered, while blue or pale green topaz is often mistaken for **aquamarine** which it closely resembles.

Colourless topaz is of small commercial importance, though a well cut specimen may be quite attractive. It is not easy to differentiate at sight from colourless specimens of quartz, tourmaline, beryl, or corundum. To the above list must be added the counterfeits—**pastes** and **synthetic corundums** of appropriate colour. Doublets representing topaz are seldom met with, though they should be borne in mind as a remote possibility.

Topaz and all the above-mentioned stones of like appearance with the exception of zircon give positive readings on the refractometer, and zircon, both on account of its distinctive appearance and its strong double refraction as seen with a lens, is hardly likely to cause difficulty in any case.

As may be seen from the figures tabulated on p. 210, **tourmaline** is the only natural mineral (disregarding such rarities as apatite and danburite) resembling topaz which gives shadow-edges in the same region as the topaz. Since the double refraction of tourmaline is double that of topaz, the two can be clearly separated by a careful reading of the maximum and minimum readings. With tourmaline, when the stone is rotated to the position where the two edges are most widely separated, they can be seen as two separate edges even in ordinary light on a standard refractometer. With topaz under these conditions the two edges are so close that they merge into one another, though a slight variation of the confused edge should be observable as the stone is rotated on the instrument.

Pastes of similar R.I. are not uncommon, and these, having a higher dispersion than topaz, will give a rather sharper and single shadow-edge. To be really certain of distinguishing between these three possibilities it is advisable to use sodium light (salt in a gas

burner in a darkened room will do) or a strong light combined with a good colour filter to get critical readings. The special spinel refractometer made by Rayner is ideal for measurements in this particular region, giving clearly defined shadow-edges in ordinary light for the natural stones, and a colour fringe with paste owing to its higher dispersion (the reverse effect, be it noted, to that seen in the standard refractometers using a lead glass hemisphere or prism). Supposing only an approximate reading of 1·63 can be obtained on the refractometer, examination of the stone under the microscope may assist the jeweller in his determination. Topaz is usually very 'clean', while tourmaline is seldom without characteristic flaw-like, liquid inclusions; the presence of spherical gas-bubbles or swirl marks, on the other hand, will prove the specimen to be a paste.

Though not used commercially, **danburite** and **apatite** can both provide transparent yellow stones, and, since they have very similar indices to those of topaz, they should be briefly mentioned for the benefit of students. With a spinel refractometer danburite can be seen to have a distinctly lower birefringence (0·006) than topaz (0·008), while the very small D.R. of apatite (about 0·002) is entirely typical for the stone. Such nice distinctions are not easily made on a standard refractometer, even in sodium light, as the scale is more cramped. Where doubt exists, resort may be had to the spectroscope or to heavy liquids. Both danburite and apatite differ from topaz in floating in methylene iodide, while in 3·06 liquid only the danburite would float. Yellow apatite shows quite a strong didymium spectrum (see Chapter 8), while danburite shows a similar spectrum, but so faintly as to be hardly visible.

The refractometer will clearly distinguish **beryl**, yellow **sapphire**, and **chrysoberyl** from topaz. Yellow chrysoberyl or yellow-green chrysoberyl is a lovely, bright stone which is curiously neglected in jewellery. It often contains crystalline 'feathers', and shows a broad absorption band in the blue-violet which serves to distinguish it from corundum should the refractometer leave any doubt. (Chapter 8.)

Before attempting a summary of the above tests, it should perhaps be mentioned that topaz has a strong tendency to cleavage parallel to the base of the natural crystal, and this fact makes it important to handle these stones with a certain amount of care,

since any sharp concussion may cause unsightly flaws to develop along cleavage planes, or even cause the stone to break. The writer has seen long drop-shaped topaz ear-rings which have broken across a cleavage plane, merely by being dropped on to the plate-glass surface of a dressing-table.

Identification of Topaz

Species	H.	S.G.	Mean R.I.	D.R.	Dichroism
Topaz	8	3·53	1·63	0·008	distinct
Zircon	7½	4·69	1·95	0·059	weak
Corundum... ...	9	3·99	1·76	0·008	weak
Chrysoberyl ...	8½	3·72	1·74	0·008	distinct
Paste*	5	3·7	1·63	none	none
Apatite	5	3·20	1·64	0·002	strong
Tourmaline ...	7	3·10	1·63	0·018	distinct
Danburite	7	3·00	1·63	0·006	weak
Beryl	7½	2·68	1·57	0·006	weak
Quartz	7	2·65	1·55	0·009	weak†
Orthoclase... ...	6	2·56	1·53	0·005	weak

* Different pastes vary greatly in their R.I. and S.G. This is one typical value.

† The majority of yellow quartzes sold owe their colour to heat-treatment. These have practically no dichroism. Untreated citrine or smoky quartz has quite distinct dichroism.

A brief résumé of the simplest methods by which topaz may be identified can now be given. The stone most frequently confused with yellow topaz is quartz (citrine). Where the stone is unset, a simple trial in bromoform will at once decide this particular issue, since quartz will float and topaz sink in the liquid. To distinguish topaz, whether yellow, pink, blue, or colourless, from all other substitutes it is only necessary to take a careful reading of the refractive index of the stone on a refractometer. If the reading is not in the 1·63 region the stone cannot be topaz; if it *is* near 1·63 then it may be topaz, tourmaline, or a paste. If two edges are discernible, showing a double refraction of about 0·02, the stone is a tourmaline. The sure distinction on the refractometer between topaz, with its small double refraction of 0·008, and paste (singly refracting) needs either monochromatic light, a good colour-filter, or a spinel refractometer. If dichroism is present, or the specimen

is found to scratch a polished quartz surface, it cannot be a paste. Under the microscope, paste will usually show a bubble or two, or swirl-like striae. Topaz, even if free from crystalline inclusions, should show enough doubling of facet edges as seen through the stone to be detected under the microscope.

In the table of physical properties of topaz and its possible substitutes given on the previous page, the rare gems danburite (pale yellow or colourless), apatite (yellow or blue), and yellow Madagascan orthoclase, are included for completeness.

IDENTIFICATION OF PINK, MAUVE, OR LILAC STONES

THE simple methods by which colourless, red, blue, green, pale blue-green, and yellow stones can be identified have now been considered and we can turn to the pink, mauve, or lilac-coloured gems which are occasionally met with in jewellery. These include **kunzite** (lilac-coloured spodumene), **morganite** (rose-coloured beryl), **pink topaz**, **pink tourmaline**, **pink sapphire** and pale mauve specimens of **amethyst** and **spinel**. **Synthetic corundum** and **spinel** of appropriate colour, **pastes** and **doublets** must also be considered in this group.

Some of these are very difficult to identify by sight alone, though the following considerations may assist in forming a decision if proper tests are not available.

Figure 71. Kunzite is often found cut very deep, as here

Kunzite is more lilac than pink, and the stone is usually, though not invariably, cut very deep to enhance the colour, which is commonly very pale. Such ill-proportioned stones are typical, and not found in any other gem; the accompanying sketch, Figure 71, made from an actual specimen, will give some idea of this peculiarity, though the actual stone looks even more 'lumpy' than in the diagram. Kunzite, too, on examination with a lens, should reveal distinct 'doubling' of the back facet edges, as the double refraction (0·015) is moderately strong. It is a difficult stone to cut, on account of its ready cleavage, and should be handled with care for the same reason. In the hands of a skilful lapidary it takes a good polish, and forms bright and attractive stones when the cutting is not too disproportionate.

The attractive pink beryl called **morganite** is more rose-coloured than lilac. As with kunzite, the colour is commonly pale, but the writer has never seen any attempt on the lapidary's part to remedy this by unduly deep cutting. This variety is usually very 'clean' and the double refraction is not strong enough to be detected with a lens, save in very large stones. **Pink topaz**, produced by heat-treatment of certain brownish-yellow Brazilian stones, can be very attractive; it has a more pronounced colour than either kunzite or morganite, takes a very high polish, and has the characteristic 'slippery' feel of all cut topaz. It is commonly cut in elongated oval shape, in accordance with the shape of the original crystal.

Pink tourmaline closely resembles the topaz, and is cut in elongated shapes for the same reason; it is seldom quite 'clean' and can often be distinguished by its typical feathery, flaw-like inclusions. (See Figure 78.) The stronger double refraction (0·018) may also be noted, causing a more pronounced 'doubling' than with topaz. Pink corundum, usually called **pink sapphire** (as sapphire properly means a blue stone, this seems rather a ridiculous contradiction in terms) is nothing more than a pale ruby, since both are simply corundums containing a trace of chromic oxide, to which the colour is due. The point at which a 'pink sapphire' becomes a pale 'ruby' is purely arbitrary, depending often upon which is the better selling name. The writer has known a case where a stone fetched a higher price as a 'fine pink sapphire' than it could command as a rather pale ruby. Pale **amethysts** are not often cut, since those of a deeper tint are so plentiful, but some specimens are very similar to kunzite in hue, though less brilliant. The colour is often unevenly distributed, being located in zones or patches.

Synthetic corundum and **spinel** are manufactured in shades of pink—the former usually an attempt to simulate pink topaz, for which it looks 'too good to be true.' Synthetic spinel when well cut forms a very bright and attractive gem indeed, and is not quite akin in appearance to any of the foregoing, though natural spinels are sometimes found in tints of pale mauve or lavender, so that a refractometer test (see under) is advisable. Finally, pastes and doublets are not uncommon in shades of pink, and may well deceive at first sight, though usually not after careful scrutiny by a practised observer.

Now let us consider the simplest tests by which these similar-looking stones can be separated and identified with certainty. On this occasion the table of constants, in which the stones are listed in order of diminishing density, will be given first.

Glancing through this table, one may see at once that, if the stones are unset, successive trials in bromoform and methylene iodide will separate morganite and amethyst from all the others, and kunzite and tourmaline from topaz, spinel, and corundum. If, as has already been recommended, a special bromoform solution matched for quartz is kept handy, amethyst can be identified outright by this means, likewise a suitable Clerici solution will identify corundum.

Table for Identifying Pink, Lilac, etc., Gems

Species	H.	S.G.	Mean R.I.	D.R.	Dichroism
Pink corundum ...	9	3·99	1·76	0·008	weak
Synthetic spinel ...	8	3·63	1·727	none	none
Natural spinel ...	8	3·59	1·715	none	none
Pink topaz	8	3·53	1·63	0·008	distinct
Kunzite	7	3·18	1·67	0·015	distinct
Pink tourmaline ...	7	3·04	1·63	0·018	distinct
Morganite	$7\frac{1}{2}$	2·80	1·59	0·008	weak
Amethyst	7	2·65	1·55	0·009	weak

Once more, however, a careful refractometer reading will provide the surest single test, and one that can be applied without removing the stone from its setting. Where monochromatic (sodium) light, or white light in combination with a good colour-filter can be used, the refractometer test alone is practically decisive for all these stones. Natural and synthetic corundum give identical readings, and may need to be examined under the microscope for a sure distinction, but synthetic spinels have a perceptibly higher index than the pale mauve natural spinels.

If a reading is given in the 1·63 region care must be exercised to separate tourmaline, with its large double refraction of 0·018 from topaz (only 0·008) and paste, which has none and thus gives only a single edge. Doublets will almost invariably give a

shadow-edge near 1·79, representing the almandine garnet which forms the table, while the back facets, if accessible, will give some such value as 1·62, according to the type of glass used for the main body of the doublet. Kunzite has sufficient separation of the shadow-edges to be clearly distinguishable from paste, the only competitor in this region of the scale for specimens of pink colour. Morganite gives higher readings and larger double refraction than other beryls, and its density is likewise higher, owing to the presence of rare alkali metals.

The figures given in the table for morganite are representative but not invariable, so that the jeweller must not be unduly troubled if his readings do not quite correspond in this instance; they will in no case overlap those of any other pink stones. As for other simple tests, the great hardness of sapphire, and the softness of paste, may be remembered. The differences in strength of dichroism in pale-coloured specimens are difficult to assess, but if perceptible dichroism is seen one may at least be sure that the specimen is not a paste, doublet, or spinel of any kind.

In summing up, one may say that of all these pink stones, kunzite and amethyst show the greatest tendency to lilac or violet tints. Without recourse to other tests, *kunzite* can usually be distinguished by its depth of cutting, distinct dichroism, and considerable double refraction, *tourmaline* by its typical inclusions and double refraction, *synthetic spinel* by its bright, clean appearance. The most decisive test for all these stones is provided by the refractometer, with subsequent microscopic examination where necessary to separate natural from synthetic corundum. Where stones are free from their setting, a trial in heavy liquids will assist in deciding the issue.

IDENTIFICATION OF BROWN AND ORANGE STONES

In the previous chapters on practical testing methods applied to particular cases we have already dealt with gems of almost every colour. Brown or orange stones, however, form a category which has not yet been covered, and since there are several gem species quite commonly found in these colours it will be as well to devote a chapter to their consideration. Practically the only gemstone of true *orange* colour is the **fire opal**; those best described as *orange-brown* include **hessonite** garnet or 'cinnamon-stone', often sold as 'jacinth', and **zircon** closely resembling it in colour, to which the term jacinth more properly applies; while the *brown* stones most commonly seen are **tourmaline** and **chrysoberyl**, apart from **quartz** and **topaz**, which can be distinguished by the methods described in Chapter 15.

As none of these stones is very costly, counterfeits are not often met with, but a **synthetic corundum** of peculiar brownish-orange tint, to which the name 'padparadscha' (variously spelt) has been applied should be mentioned, though whether intended to represent garnet, topaz, or zircon is something of a mystery. The author once encountered a complete necklace of these things, faceted and mounted in gold. **Natural corundums** which might be described as orange are only very occasionally found.

Unlike other opals, **fire opal** usually shows no play of colour; it has little brilliance to recommend it, and thus its chief claim to beauty lies in its magnificent flame-red colour. The best specimens are almost completely clear, though a slight milkiness is often apparent. The cutting most usually adopted is a step- or mixed-cut with a slightly domed table facet. This last peculiarity militates against a test with the refractometer unless the stone is free from its setting, when one of the flat back facets can be applied to the instrument. Being amorphous, fire opal shows no dichroism or double refraction, and in this it tallies with the imitations sometimes made in **glass** or one of the plastics such as **Bakelite**.

If a stone is under suspicion it is best to remove it from its setting and test its refractive index and density, both of which, in

true fire opal, are fairly constant and characteristic. It may be possible to obtain a refractive index reading for fire opal even if it has a domed table by using the 'distant vision' technique, though this is usually more easily carried out with stones having a surface with steeper curvature. Under the microscope, glass will usually reveal bubbles or striae, and any of the plastics will peel under the blade of a pen-knife, carefully applied—the degree of toughness varying according to the type of plastic. (See p. 267 *et seq.*)

The commonest plastics vary in density from 1·25 to 1·45, far lower than fire opal (2·00), and, contrariwise, they have a higher refractive index—1·49 to 1·65 as against 1·45. Such imitations are seldom seen except in fancy jewellery. Other tests for fire opal will be found in Chapter 18.

The two stones to which the unsatisfactory name 'jacinth' is most commonly applied, namely, orange-brown **hessonite** garnet and **zircon** or 'jargoon', are very similar in appearance. The cinnamon garnet (the jeweller's 'jacinth') can usually be recognized by its multitude of small inclusions, which give it a peculiar granular appearance (Figure 74, p. 230), while zircon has its own characteristic resinous-adamantine lustre and large double refraction. The dichroscope is of little value here, as garnet is a cubic mineral and therefore non-dichroic, and no zircon except the blue variety shows perceptible dichroism. On the refractometer, hessonite normally gives a reading near 1·743, but the presence of the almandine molecule may raise the index. Almandine-rich hessonites have a distinctly reddish tint, and show the easily recognized almandine absorption spectrum.

A rare but exciting possibility is that a seeming hessonite may turn out to be yet another member of the large garnet family: **spessartite**. Fine specimens of this manganese garnet are so scarce as to command relatively high prices amongst discriminating collectors. The refractive index and density of spessartite are very near those for almandine (e.g., 1·79 and 4·10), but the colour is quite different, being yellow, orange, or orange-brown, instead of deep, purplish red.* Zircon, with its high refractivity, gives a 'negative' reading on the ordinary refractometer—that is, a shadow extending right up to the edge representing the contact

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* Also, bands due to manganese may be seen in the blue and violet of its absorption spectrum (Chapter 8).

liquid used. This, if considered in conjunction with the appearance of the stone, is virtually conclusive, but brown **sphene** should be borne in mind as a possibility, since this also will give a negative refractometer reading, and shows even stronger double refraction, though this is sometimes masked, so far as doubling of facet edges is concerned, by the complete absorption of one ray. The dichroscope here will settle any doubt, since brown sphene is strongly dichroic while zircon of this tint is virtually non-dichroic.

Brown specimens of **peridot** (the mineralogist's olivine) are extremely rare. They have nearly the same properties as the normal green peridot. Most of the stones formerly thought to be brown peridot are now known to belong to the recently recognized species **sinhalite**. Sinhalite was the second new mineral to be originally discovered as a faceted gemstone, though rough pebbles of sinhalite have since been recovered from the gem gravels of Ceylon, the connection with which is signalized in its name.

Sinhalite is a magnesium aluminium borate, and crystallizes in the orthorhombic system. It can be found in quite large pieces, and varies in colour from a pale straw yellow to dark brown. The most attractive specimens are golden yellow with a greenish cast, rather resembling chrysoberyl or zircon. Specimens of sinhalite have, in fact, been found in parcels labelled 'zircon', 'chrysoberyl' and 'tourmaline'. Both the refractive index range and the density are higher than for peridot, and the absorption spectrum, although very similar (signifying its very similar crystal structure) has an 'extra' band at 4630 Å in the blue, not found in the three-band spectrum of peridot. Once its existence and its properties are known there should be no great difficulty in distinguishing sinhalite from stones which resemble it.

If we consider every possibility, **diamond** and **cassiterite** are two other minerals which give negative readings and can fall in this colour category. Brown diamond, with its brilliant adamantine lustre, single refraction, and incomparable hardness (see Chapter 9), should be easy to distinguish, and cassiterite, valuable as an ore of tin, as a gemstone must be considered a freak. As can be seen from the comparative table overleaf, it has a density far higher even than zircon.

The two other common gemstones which come under this colour-group, brown **tourmaline** and brown **chrysoberyl**, are often very difficult to distinguish at sight. Both are more sheerly

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brown than the stones already discussed, and are indeed not very attractive. Tourmalines of this type absorb a great deal of light, and for this reason are very 'dead' in appearance. The doubling effect which can be detected with a lens in most tourmalines cannot be seen here, since one of the two doubly refracted rays (the 'ordinary' ray) is so completely absorbed within the stone. The dichroscope image corresponding to this ray is therefore practically black, in contrast to the other image, which is brown. The refractometer as usual provides the most positive test for these two minerals; tourmaline showing two shadow-edges near 1·62 and 1·64 at their widest separation, while chrysoberyl has much higher indices, near 1·74 and 1·75, with a double refraction too small to be distinguished unless monochromatic light be used. Here again, an exciting but unlikely possibility exists for the wide-awake jeweller. The mineral **andalusite**, very occasionally cut as a gem, has properties close to those of tourmaline, and may present a very similar appearance, though it is an entirely distinct mineral. Tourmaline belongs to the hexagonal (trigonal) system of crystal symmetry, while andalusite is orthorhombic—a fact which provides the mineralogist with quite conclusive optical means for distinguishing the two. But a simple refractometer reading, if carefully taken, will also enable a definite distinction to be made, since tourmaline of 'andalusite' colour (brown or brownish-green with hints of red) will always show a double refraction nearly twice as great as that of andalusite. The matter is given space here, because dealers have sometimes attempted to satisfy collectors' inquiries for an andalusite with tourmalines of suitable appearance from their stock, not realizing that the collector is a discriminating person, and desires an andalusite *qua* andalusite, and not simply for its appearance!

Other brown or orange stones occasionally cut for collectors are **blende** or **sphalerite**, and idocrase. Blende is a cubic mineral having a refractive index nearly as high as that of diamond, and its dispersion is considerably higher, but its softness and its ready dodecahedral cleavage make it difficult to cut to good advantage and incapable of standing any wear. Its high single refraction distinguishes it from everything save diamond, with which its appearance hardly allows it to be confused. The colour generally shown by transparent pieces is a magnificent golden brown. Occasionally it displays an absorption spectrum in which one or

more narrow bands can be seen in the red. This is mentioned lest the beginner might confuse these with rather similar bands seen in zircon.

Idocrase at its best can be an attractive gem and is sufficiently hard to take and maintain quite a good polish. Stones from the Laurentian Mountains in Canada are of a clear golden brown. They may be distinguished by their refractive index of a little above 1·70, with a very small double refraction (0·005). Some specimens may show a faint didymium absorption spectrum.

Identification of Brown and Orange Stones

Species	H.	S.G.	Mean R.I.	D.R.	Dichroism
Cassiterite ...	$6\frac{1}{2}$	6·9	2·04	0·10	distinct
Zircon	$7\frac{1}{2}$	4·69	1·95	0·059	v. weak
Spessartite ...	7	4·16	1·80	none	none
Blende	$3\frac{1}{2}$	4·09	2·37	none	none
Corundum ...	9	3·99	1·76	0·008	weak
Chrysoberyl ...	$8\frac{1}{2}$	3·71	1·75	0·009	distinct
Hessonite ...	$7\frac{1}{4}$	3·65	1·74	none	none
Topaz	8	3·53	1·63	0·008	distinct
Sphene	5	3·53	1·96	0·12	strong
Diamond ...	10	3·52	2·42	none	none
Sinhalite ...	$6\frac{1}{2}$	3·48	1·69	0·038	weak
Idocrase ...	$6\frac{1}{2}$	3·38	1·70	0·005	distinct
Andalusite ...	$7\frac{1}{2}$	3·15	1·64	0·010	strong
Tourmaline ...	7	3·07	1·63	0·018	strong
Quartz	7	2·65	1·55	0·009	weak
Fire opal ...	$5\frac{1}{2}$	2·00	1·45	none	none

QUARTZ, OPAL, AND THE GARNETS

QUARTZ is the commonest, but nevertheless one of the most beautiful, of all minerals. It is composed of pure silica (silicon dioxide: SiO_2), a compound which, either alone or combined in the form of silicates, accounts for nearly 60 per cent of the earth's crust. Quartz is also a very durable mineral both chemically and physically, so that when rocks become weathered and broken down after long ages of exposure, grains of quartz remain and form the bulk of the river gravels, the sands of the seashore, and the sands of the desert.

The jeweller knows quartz in many forms, though he may not realize that all these belong to the same mineral species. The quartz minerals fall into two categories:

(a) Crystalline quartz, occurring as individually visible hexagonal crystals—typified by rock crystal, amethyst, and citrine, etc.

(b) Cryptocrystalline quartz, typified by chalcedony, agate, chrysoprase, cornelian, etc.

Stones belonging to this second group are composed of tiny grains or fibres of quartz too small to be distinguished as individuals. The varieties in these two groups are too numerous to allow for detailed discussion of each, and from the point of view of identification this is in any case unnecessary. The crystalline forms of quartz used in jewellery are for the most part transparent. Their properties are remarkably constant, and are as follows: hardness—the standard 7 on Mohs' scale; specific gravity—2·651; refractive indices—1·544 and 1·553.

If the reader has provided himself with a bromoform mixture matched exactly with a rock-crystal indicator, as suggested earlier in the book, he will be able to identify any pure specimen of the crystalline quartzes (provided it is free from its setting) by a trial in this liquid. If a refractometer is available and the stone is faceted the refractive index will also be found a reliable guide.

Before mentioning particular varieties and the other minerals with which each may be confused, it will save needless repetition if the distinction of any of them from **glass** imitations is dealt with first, *en bloc*. Quartz gemstones, on account of their low

refractivity, have a very glassy lustre, and are thus difficult to distinguish from glass counterfeits by inspection alone. One simple test which is remarkably effective when properly applied arises from the low heat-conductivity of glass. If a specimen of quartz and one of glass be touched with the tongue, quartz will feel perceptibly the cooler, and the same will prove true for any of the crystalline gemstones, since they all conduct heat away from the spot touched by the tongue at a rate faster than glass does. Amber and other resins conduct heat even less than glass, and thus feel still warmer to the touch. Naturally certain precautions are necessary in carrying out such a test. Hygiene demands that the specimens should be in a clean condition, and they must not be warm from recent contact with the hands. Each stone should be held in corn-tongs for the test, and a direct comparison made with a known specimen of quartz, since glass also feels cold to the tongue and is only warm in comparison with true crystal. Other features by which glass can be recognized—bubbles, swirl-marks, etc., have already been described in Chapter 6. Most coloured quartzes are dichroic, and if dichroism is detected this of course puts glass out of court.

Some of the crystalline varieties of quartz can now be individually mentioned and a brief reference made to stones with which they may be confused. The colourless quartz called **rock-crystal** is too insipid to make a satisfactory gemstone, but it is a beautiful material for carvings, beads, crystal balls, and the like. Glass is the only likely substitute. The yellow quartz properly known as **citrine**, though commonly sold under the misnomer 'topaz', is easily mistaken for that more precious mineral. Density and refractive index tests each provide a clear separation. Most citrines have been produced from amethyst by heat treatment, the colour-change being permanent. Such stones show practically no dichroism, whereas natural yellow quartz is distinctly dichroic. Citrine grades into the darker brown **cairngorm** or the smoky **morion**. A clear green form of quartz has recently been marketed, for which the name '**prasiolite**' has been proposed. This is derived from certain types of amethyst found in Minas Gerais, Brazil, by careful heat treatment. The stones have some similarity to beryl or tourmaline in appearance, but have all the ordinary distinguishing features of quartz. **Amethyst** varies in tint from pale mauve to the deepest violet. Patchiness and zoning of colour

will distinguish it from paste, as also will doubling of the table facets, when viewed with a lens. Purple sapphire (miscalled 'Oriental amethyst') is sometimes seen in similar colours, but is a far brighter, harder stone, with the higher R.I. and S.G. of corundum.

Rose quartz is never quite transparent, but milky and often veined and flawed. When deep in tint it makes attractive beads and is a lovely material for small carvings or ornaments. If suitably cut, a six-rayed star is not uncommonly seen in rose quartz,
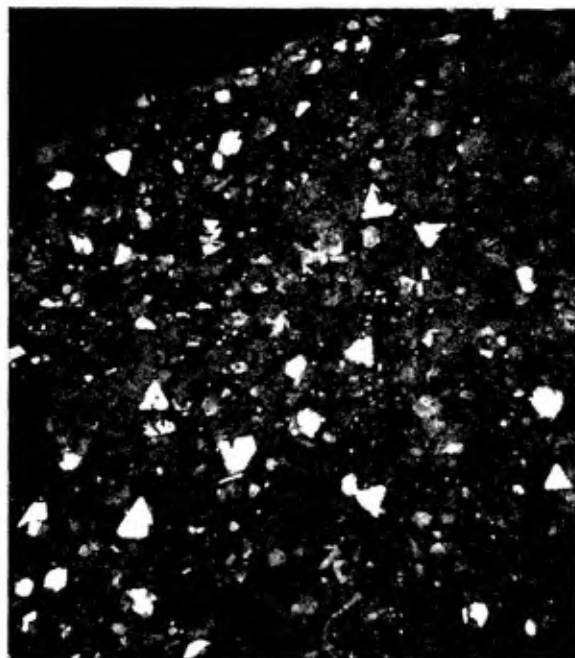
Figure 72. Copper crystals in aventurine glass

though never very strongly marked. The effect has been ingeniously enhanced in recently made doublets in which a hemisphere of asteriated quartz is provided with a reflecting base. The resulting doublet presents a very striking appearance, with a brilliant star effect.*. This has been found to be due to extremely fine

* The effect here is produced more by the transmitted light (diasterism) than by the reflected light (epiasterism).

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needles of rutile oriented in three directions at right-angles to the trigonal symmetry axis of the crystal.

It can be easily distinguished from star sapphire at sight, not only by the greater brilliance of the star, but also by the fact that when viewed under an electric light a reflection of the electric light bulb can be clearly seen at the centre of the star—an effect not seen in untreated star stones. Later productions are more deceptive, though the rays are less well defined than in genuine or synthetic star sapphire, and the pink colour of the quartz can be seen when viewed at right-angles to its axis.

Quartz cat's-eyes contain parallel fibres or canals where fibres once were. Their usual colour is fawn-brown, greenish, or yellowish, and the ray, though distinct, is not so sharp or silky as with chrysoberyl cat's-eye because the reflecting fibres are coarser. A fine quartz cat's-eye is very similar in appearance to a poor chrysoberyl cat's-eye, though the latter has a brighter surface lustre. If the stone is unset, a density test in bromoform or methylene iodide will provide a clear decision in such cases. When in a setting, the 'distant vision' method will distinguish between them on the refractometer. Impure cat's-eye quartz has been stained various colours, the products being sold as 'Hungarian cat's-eyes'. The magnificent golden brown chatoyant **tiger's-eye** was originally a blue crocidolite asbestos, the fibres of which have since been replaced by quartz. The name crocidolite is often retained for the altered material. Fibres of reddish-brown rutile are often seen penetrating a colourless quartz in apparently random orientation. This rutilated quartz is known by such fancy names as 'Venus's hair stone' or 'flèches d'amour'. Continuing the list of quartzes containing inclusions, there is a green **aventurine quartz**, which owes its colour and spangled appearance to the presence of small flakes of green fuchsite mica, and there is a reddish brown aventurine quartz containing spangles of an iron oxide mineral. The golden brown **aventurine glass** so frequently seen has S.G. and R.I. near that of quartz, but is far more spectacular than any natural aventurine. (See Figure 72.)

Rock-crystal beads are sometimes heated and cooled suddenly by plunging into water containing dye-stuffs. The colour enters the cracks formed by the sudden chilling, and the resulting effect is quite pretty, though obviously 'faked'. **Jasper** is a very impure opaque quartz, usually some shade of brown in colour. Jasper

artificially stained with Berlin blue is used as an imitation for lapis lazuli, and is known as Swiss or German lapis.

Passing now to Group (b), the chalcedony group: here again we have a host of names to contend with for what is essentially the same material. The differences are chiefly in colour and types of banded structure. Cryptocrystalline quartz when translucent and unbanded is known as **chalcedony.** The density (about 2·60) and refractive index (about 1·535) are slightly lower than for quartz. Careful observation on the refractometer will show a small
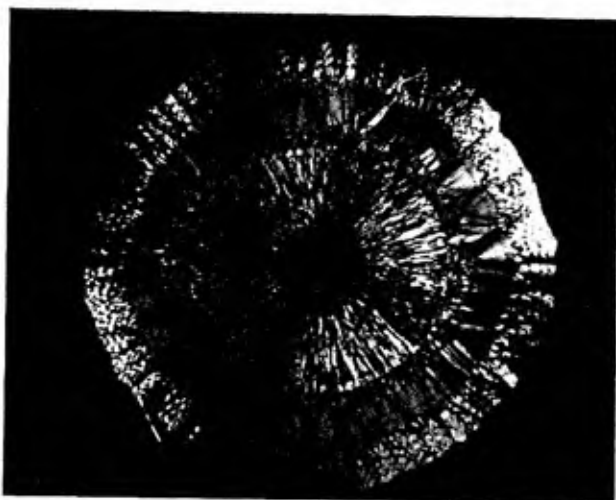
Figure 73. Chalcedony section as seen between crossed Nicols

amount of double refraction in certain specimens, which argues a considerable degree of order in the arrangement of the fibres.* The cryptocrystalline structure of chalcedony can be seen most clearly in thin section between crossed Nicols under the microscope. A chalcedony stalactite photographed under these conditions is reproduced in Figure 73. Unlike crystalline quartz, the cryptocrystalline types are to some extent porous and thus susceptible to staining; full advantage is taken of the fact to 'improve'

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* Though X-ray analysis shows chalcedony to be essentially quartz, it is curious that the optical properties are distinctly different.

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the dim and delicate colourings found in nature. Chalcedony itself is mostly stained in shades of blue or green. The blue is sometimes miscalled 'blue moonstone'; the green is produced by treatment with chromium salts and appears pink under the Chelsea colour-filter—thus distinguishing it from chrysoprase and from jade, for which it is sometimes wrongfully sold. Vague narrow bands due to chromium can be discerned in the absorption spectrum of this green chalcedony.

True **chrysoprase** owes its (natural) apple-green colour to a compound of nickel. Though common enough in its poorer qualities, really fine pieces are comparatively rare and valuable. **Agate** is the best known of the banded chalcedonies. The layers are curved and follow the shape of the rock-cavity in which the silica was deposited in a series of rhythmic stages. Agate is extensively used industrially in the manufacture of balances, for pestles and mortars, etc., the natural colour being retained for such purposes. When required for ornament it is stained by a variety of chemical means to enhance the contrast of the various layers. Where the bands are straight, the names **onyx** (black and white), **sard** (red), **sardonyx** (red and white), are used. Cameos are often cut from such material, the carved relief being worked in the white layer with the underlying black or red layer acting as an effective background. Black onyx is produced by saturation of the natural greyish material with a solution of sugar or honey, and subsequent treatment with sulphuric acid, which deposits carbon in the pores of the stone.

Cornelian, a more correct version of the usual spelling carne-lian, is a reddish or yellowish-red chalcedony which shows a banded structure by transmitted light. **Moss-agate** is the name given to black dendritic (fern-like) growths of manganese dioxide in a milky white translucent chalcedony which is only faintly banded. Such growths often mimic plant life to an astonishing degree. There are many other names given to members of the chalcedony group which have not been included above, but their use in jewellery is not at all extensive.

OPAL

'All the colours of the rainbow' is, in the case of opal, not merely a catch-phrase, since the colours seen are not the mixed residual

colours due to ordinary partial absorption of white light, but gleams of almost pure spectrum colour composed of a narrow band of wavelengths which alone of all the waves in the incident light have not been destroyed by 'interference' after reflection from thin films within the stone. The particular colour which reaches the eye varies, as is well known, with the angle at which the stone is viewed. By *transmitted* light none of these colours can be seen. Raman and Jayaraman have recently found that the structure of opal contains thin layers of two different modifications of silica, low-tridymite and high-crystobalite, which vary slightly in refractive index. When the size and spacing of these thin crystallites are of the right dimensions, brilliant flashes of monochromatic colour are produced by reflected light. Examination of these reflecting patches with a lens or microscope will reveal the lamellar, striated structure of these internal layers.

As regards identification, there is little that need be said concerning opal, since, except in the variety fire opal, it is a stone that cannot effectively be imitated. Crude imitations of white opal are sometimes seen, consisting of coloured tinsel within an opalescent glass, but the veriest tyro would hardly be deceived by these.

Opal as used in jewellery can be divided into four types: black opal, white opal, Mexican water opal, and fire opal.

Black opal is the most highly prized, and with its flashes of almost pure spectrum colour gleaming out of a sombre background appeals to many connoisseurs above all other jewels. Often the brilliant play of colour is found only in very thin layers, and to provide a stone of sufficient thickness and strength for setting, such slices are commonly cemented on to a base of less precious black opal matrix, or on to black onyx. The first forms a true opal doublet, while the second should properly be termed an opal-on-onyx doublet. Since such composite pieces are naturally less valuable than single stones of equivalent size and appearance, in purchasing a stone one should examine it carefully with a lens to ensure that it is all in one piece. Usually these doublets have a very flat table.

White opal, in which the background to the colour-flashes is milky white or grey, is found in thicker pieces, and there is less likelihood of a doublet being found in this material.

Mexican water opal is a variety seldom mentioned in books, and is not so popular as its beauty merits. It is often practically

transparent, appearing yellowish by transmitted light, but from within the stone come lovely flashes of vivid colour, changing, as in all opals, when the stone is viewed from different angles. There can be no question of imitations here.

Fire opal on the other hand, is difficult to distinguish at sight from glass or a synthetic resin (plastic) such as Bakelite, of similar colour, since normally there is no 'play of colour' to be found in a fire opal, the attraction of which rests upon its fine flame-red or orange tint.

With regard to tests, it has already been stated that none should be necessary except with fire opal. Here, as the table facet is often domed, a refractometer reading may not be obtainable. If a fire opal (in its setting, if need be) is immersed in a cell, or dish, or cup, containing carbon tetrachloride (a colourless liquid well known as a dry-cleaning agent and fire extinguisher) the refractive index of the stone and the liquid are so closely matched that the edges of the facets and outlines of the stones will be hardly visible, where the R.I. of either a Bakelite or glass imitation will be sufficiently high to show the outlines of the facets fairly distinctly. If the stone is free from its setting, the density of fire opal, which is almost exactly 2·0, is sufficiently different from that of Bakelite (1·26) and other plastics, which are also far less dense, to make distinction easy.

A so-called **'opal glass'** has been manufactured which has both R.I. and density only a little above that for true opal, but it is generally a milky white or yellow, and the glass used for imitating fire opal has a density of 2·4 or higher.

Since opals are to some extent porous, it is most inadvisable to test them in heavy liquids, which may ruin their beauty. Fire opals, however, are not harmed by a brief immersion in a bromoform-benzene mixture, provided they are cleaned immediately afterwards; and a hydrostatic determination using pure water will do no permanent harm to any opal, though it may alter in appearance temporarily while still wet.

The properties of opal may be briefly stated, for convenience. In composition it is an amorphous form of silica containing a variable amount of water. Its hardness is about 6, and refractive index near 1·45. The density of water opal and fire opal is near 2·00 and of black and white opal about 2·11, though differences in porosity may lead to much lower figures for certain specimens.

THE GARNETS

The name garnet is given to a group of minerals crystallizing in the cubic system which vary widely in their chemical constituents but which all conform to the same general type of chemical formula and crystallize in the same forms. Mineralogists recognize six distinct members of this group: grossular (hessonite), pyrope, almandine, andradite (demantoid), spessartite, and uvarovite. All of these except the last have been used as gems, though cut specimens of spessartite are extremely rare. The garnets provide an excellent example of what is known as isomorphous replacement—that is, the replacement of one element by another chemically similar element in a mineral without appreciable disturbance of the crystal form or structure. Almandine (an iron-aluminium silicate) and pyrope (a magnesium-aluminium silicate) in particular are never found in a pure state, but always intermingled, often with some of the other garnet molecules present in small amount. It is indeed a matter of opinion whether certain red garnets should be called almandines or pyropes, the term 'almandine-pyrope', though cumbersome, being more correct than either. Though the author has often deprecated the irresponsible addition of new gem names to the literature, in this case he is tempted to suggest the portmanteau term 'pyrandine' garnet for the red garnets with refractive index between 1·75 and 1·78, to which no name in current use properly applies. This could cause no confusion with the name of any other gem, and its derivation is sufficiently obvious, though for the sake of euphony the first syllable would have to be pronounced short.

Colour, density, and refractive index form a clear enough guide in distinguishing between the other garnets, and these criteria also serve to avoid confusion with other gem minerals. Being cubic, all the garnets are singly refracting and show no dichroism. Their other distinguishing characters are better considered separately in the brief description of each variety which follows.

Hessonite or cinnamon-stone is the orange-brown variety of grossular garnet to which in the trade the ambiguous term 'jacinth' is frequently applied. The distinctions between hessonite and the zircon and other stones of similar hue has already been described in the last chapter. The peculiar grannular appearance of hessonite, arising from numerous small transparent inclusions, is a

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feature which assists the observer to recognize it at sight. The appearance of these tell-tale inclusions under a low-power micro-scope is shown in Figure 74. In addition the internal structure of hessonite has a curious, treacly, fused appearance. A massive* green variety of grossular found in South Africa resembles jade and has been called 'Transvaal jade' on that account. It has a refractive index of 1·72 and density 3·47—figures which distin-guish it clearly from the true jade minerals, jadeite and nephrite.
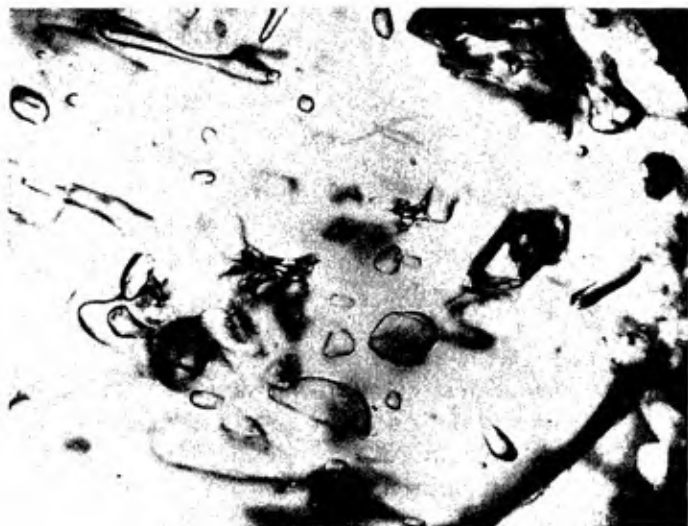
Figure 74. Inclusions in hessonite garnet

Of the red garnets, **pyrope** has undoubtedly the finest colour, if one includes under this name only those comparatively 'pure' pyropes from Kimberley, Arizona, and the former Bohemia. All of these owe their colour principally to the presence of chromic oxide, the colouring agent to which the fine red of ruby and of red spinel can also be credited. Pyrope is seldom found in large sizes, and its colour though fine is often too dark to be appre-ciated. The single refractive index of near 1·745 is sufficiently above that of almost all **red spinels** to make distinction easy, though confusion between the two has been reported, even by

* The term 'massive' is used by mineralogists to denote a compact aggregate showing no crystal form.

trained mineralogists. The author has recently investigated this particular question in some detail and is firmly of the opinion that if both the density and refractive index of the specimen are accurately determined the distinction of spinel from garnet is always possible. The lowest constants for any pyrope measured were found to be 1·732 for the refractive index and 3·643 for the density. This was for one particular specimen from Fort Defiance, Arizona, and was quite exceptional, the average figures for other specimens from the same locality being 1·744 and 3·70. Only *one* red spinel of many hundreds measured had a refractive index as high as this lowest pyrope. This particular spinel (from Mogok, Burma) had R.I. 1·734 and S.G. 3·611.

It can thus be said that even in such very exceptional stones, in which a refractometer test alone would admittedly not allow a decision to be made, the density of the spinel is definitely lower than that of the pyrope garnet. Quite 90 per cent of the red spinels examined had refractive index 1·720 or lower, and there need be no question of pyrope in such cases. An additional check is in any case available in the absorption spectra of the two stones, though at first glance they are very similar. The most notable feature in each is a broad band near the centre of the spectrum. In pyrope this band is centred at about 5750 Å, that is, in the yellow-green, whereas in spinel the band is nearer to the blue, being centred at about 5400 Å. In pyrope, the strongest of the almandine bands can be detected in the blue-green at 5050 Å, and this of course is never seen in a spinel. A simple method for checking the position of the broad band in pyrope or spinel in order to distinguish the two is to interpose a very dilute solution of potassium permanganate, contained in a bottle or beaker, between the light source and the stone. When suitably diluted, the permanganate will show five evenly spaced absorption bands centred at 5710, 5460, 5240, 5040 and 4860 Å.

These act as a 'built-in' wavelength scale and by placing the stone in and out of the field, comparison with the permanganate bands makes it obvious whether the absorption of the stone is near 5400 (spinel) and 5750 (pyrope). Crookes glass (often used in anti-glare spectacles) can be made to function in the same way, since the glass shows clear-cut absorption bands due to didymium. The strongest of these is at 5840 Å, and makes a useful standard for comparison.

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Perhaps a simpler test which distinguishes red spinel from pyrope is its red fluorescence under ultra-violet light or under the more sensitive test of 'crossed filters'. Pyrope, due to its iron content, is completely non-fluorescent. The red glow of spinel when strongly illuminated in light which has passed through a flask of copper sulphate can be resolved by a prism spectroscope into a closely-spaced group of narrow bright lines. This 'organ-pipe' fluorescence spectrum is a very diagnostic test for red spinel.

This particular case has been discussed at some length because it is one of the few instances where the standard methods of gem testing have been seriously challenged and recourse to chemical analysis suggested. The author strongly holds the view that this should never be necessary.

Apart from pyropes coloured by chromium there is a whole series of red garnets, as previously mentioned, forming the almandine-pyrope range, in which the refractive index and density become progressively higher as the proportion of the almandine molecule present becomes greater. The colour of **almandine** is a peculiar purplish red, so deep in tint in the heaviest types that stones appear almost black unless backed by a reflecting layer of foil. Such stones have been often cut as hollow cabochons, for which the name 'carbuncle' has been used for centuries. The highest figures for red garnets used in jewellery are about 4·20 and 1·81 respectively for density and refractive index, corresponding to a garnet containing some 80 per cent of the almandine molecule.

The gemstones most likely to be confused with almandine are **Siam ruby** and purplish red **spinel**, both of which may have a very similar colour. The spinel is easily separated by its lower constants, but those of the ruby are very close to certain almandines. Ruby is doubly refracting, and a refractometer reading will enable a clear decision to be made if carefully taken in sodium light. The dichroscope is also helpful here, although the dichroism of Siam rubies is weaker than in rubies from Burma. A useful test is provided by the spectroscope, since the almandine spectrum of three strong bands is easily distinguished from the ruby spectrum of one broad band—accompanied by very narrow bands in the red and in the blue. Almandine typically contains rod-like crystal inclusions which are parallel to the dodecahedral faces of the original crystal, and thus intersect at an angle of 60 degrees—

rather reminiscent of the 'silk' in Burma ruby, but on a coarser scale, and in three dimensions in place of two. These are often seen in the slice of almandine used to form the table facet of a doublet (see Chapter 6) with a layer of bubbles immediately below, where the junction with the glass base occurs. Inclusions of another type are shown in Figure 38.

The green variety of andradite known as **demantoid** is the most highly prized of the garnets in commercial use, and fine specimens of 2 carats upwards are exceedingly hard to obtain. In the trade, the name 'olivine' is widely used for this green garnet—an unfortunate misnomer, since olivine is a name well established by mineralogists for quite another mineral, of which peridot is the gem variety. The name of 'demantoid', which is unequivocal and therefore preferable, has a fine ring to it, and

Figure 75. Absorption spectrum of almandine

one would expect it to have quite as good a selling value as the softer-sounding 'olivine'. Green garnet has the high refractive index of 1·89 and a dispersion higher than diamond, giving it liveliness and fire. The density is 3·85 and these properties vary only slightly, as this species alone among the gem garnets does not suffer extensive replacement by other garnet molecules. The colour of demantoid is yellowish to bright leaf green, always with more tendency to yellow-green than the bluer green of emerald, from which its appearance differs quite sufficiently to render confusion unlikely by those familiar with both these gemstones. There are indeed few other species for which the green garnet is likely to be mistaken by anyone who is at all experienced. **Sphene** perhaps resembles it more closely than any other, on account of its life and fire. Scrutiny with a lens, however, will at once remove any doubt, since sphene has the strongest birefringence of any gem, while demantoid is singly refracting.

Green zircon may also be confused with demantoid, since the colour is rather similar and there is enough dispersion to give the

stone considerable 'life'. Green zircon is almost invariably of the low or intermediate type (see Chapter 14) and with these double refraction may not be visible with a lens, though sharp extinction between crossed Nicols will be observable in most cases. The spectroscope will reveal a rather woolly band in the orange-red with these zircons and possibly other zircon bands in addition. Some demantoids may show an absorption 'doublet' in the deep red and fainter bands in the orange—all due to chromic oxide to which the fine green colour can be attributed—but the most
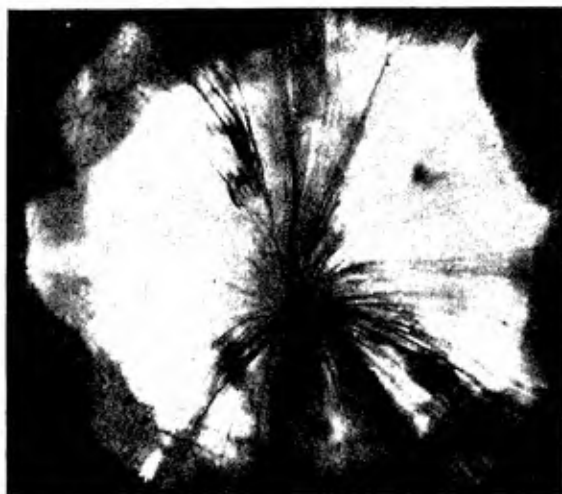
Figure 76.   Asbestos fibres as inclusions in demantoid garnet

constant feature of the demantoid spectrum is an intense absorption band at 4400 Å in the violet which may only be visible as a sharp cut-off to the end of the spectrum.

A peculiarity of demantoid is the nature of its inclusions. Careful scrutiny with lens or microscope will reveal these as wisps of tiny silky asbestos fibres, often radiating from one or more centres.

If a parcel of demantoids is carefully examined, almost all specimens will be found to contain at least some of these fibres, and they provide a very practical aid to identification. The microscope will of course show the inclusions more plainly; a photomicrograph of a typical specimen is reproduced in Figure 76 and will give the reader a good idea of their nature. **Peridot** has

rather the same colour as demantoid, but is lacking in 'fire', and once again the 'doubling' of the back facets will serve as a quick confirmatory test.

The rare manganese garnet, **spessartite**, has already been mentioned under 'Brown and Orange Stones' in the preceding chapter. It resembles hessonite garnet rather closely, but lacks the granular inclusions, has a more beautiful and subtle colour, and can be clearly distinguished by its higher refractive index (1·80) and density (4·16). Spessartites from Ceylon, which attain the largest sizes, have a tinge of almandine colour mixed with the orange, but smaller specimens from Virginia and Brazil may be a clear yellow or orange without any trace of red, and these have slightly higher constants than those just given.

Spessartites of any colour show strong absorption bands in the blue and violet, often in addition to faint almandine bands. The strongest visible absorption is at 4320 Å. Dr E. Gübelin finds the inclusions of spessartite to be sufficiently distinctive to identify the mineral. These are difficult to describe, but appear rather like shreds of a black mantilla shawl which has been torn to pieces and scattered at random through the stone.

The last of the six garnets, uvarovite, is a chromium garnet and for that reason has a fine green colour, though crystals of this garnet are not found in sufficiently large transparent pieces to allow for its being cut as a gemstone. The presence of the uvarovite molecule in demantoid gives it an attractive green hue, though, curiously enough, in pyrope the presence of chromic oxide produces only a deep red.

TOURMALINE, PERIDOT, AND SPINEL

TOURMALINE is one of the most attractive of minerals and is very widely distributed, though only in relatively few localities is it found in transparent pieces suitable for cutting into gemstones. Its striated prismatic crystals, with their rounded triangular cross-section, are very easily recognized.

The mineral has an exceedingly complex chemical composition, and it cannot easily be expressed as a formula: but this apparent complexity is due to the many substitutions of one kind of atom for another that can take place in the crystal lattice. Broadly speaking it can be described as a borosilicate of aluminium containing variable amounts of magnesium, iron, and the alkali metals. The colour gives an indication as to whether a given tourmaline belongs to the iron-, magnesium-, or alkali-rich type, and there are corresponding slight differences in density.

The alkali tourmalines are the most important from the gem point of view, being mostly pink, red, or pale green. These have the lowest density, varying between 3·01 and 3·06. The magnesium tourmalines are brown and have a density of 3·04–3·10, while iron-rich types are deep greenish-blue to black and have a density of 3·08–3·20.

Besides the colours mentioned, yellow tourmalines are sometimes found, and also colourless or nearly colourless stones. Variety names are sometimes used for some of these coloured tourmalines—rubellite for the red, indicolite for the blue, achroite for the colourless, and schorl for the black: but it is preferable to use the simple colour descriptions 'red tourmaline', 'blue tourmaline', etc., since there can then be no confusion.

The refractive indices of tourmaline are usually near 1·62 and 1·64, with an average separation of 0·018 between the two readings. It must be remembered that it may be necessary to try the stone in different orientations on the refractometer to obtain the maximum double refraction. In the direction of the optic axis there is only single refraction, giving a reading for the higher index, corresponding to the 'ordinary' ray. This edge remains constant if the stone is rotated on the instrument, while the edge corresponding to the 'extraordinary' ray will be seen to move to

a minimum position and then back again. The extent of the D.R. in tourmaline is of great practical importance, as it serves to distinguish this mineral from others of similar refractivity but lower birefringence, notably topaz and the rare minerals andalusite (0·01), apatite (0·002), and danburite (0·006), not to mention the singly refracting pastes which quite often have a refractive index in this region. Text-books often quote 0·025 as the D.R. o tourmaline, but in transparent stones so high a value is never encountered, though in black, opaque tourmalines the birefringence may be 0·03 or even higher. The author and Mr. C. J. Payne have carefully measured the indices of a large number of tourmalines
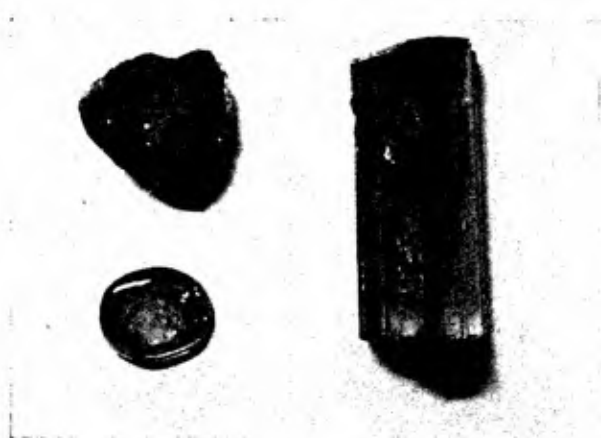
Figure 77. Specimens of tourmaline showing crystal form and colour zoning. The smallest piece has been polished

of all available colours, and found 0·022 to be the maximum birefringence while the lowest value was only 0·014, given by two brownish red tourmalines which were optically anomalous, giving a distinctly biaxial interference figure.

Putting the matter briefly, any transparent gemstone having a mean refractive index of about 1·63 and a birefringence of between 0·015 and 0·020 may safely be taken as a tourmaline. The fact that only the lower index edge moves when the stone is rotated is an additional sign. If the table facet should happen to have been cut at right-angles to the optic axis, both edges will remain stationary during rotation, the edges being in their position

of maximum separation the whole time. If, as often happens in practice, the optic axis is parallel to the length of the cut stone, then only a single edge will be visible in this direction, and maximum separation will be found when the stone is rotated to a position 90° from this.

The double refraction of tourmaline is strong enough to cause a doubling effect of the back facet edges when carefully examined with a lens through the front of the stone, unless the specimen is very small.

The effect is masked in a deep brown or green stone, due to the complete absorption of the 'ordinary' ray. The strong absorption

Figure 78.   Typical inclusions in tourmaline

of this ray can be seen in the dichroscope with brown stones, when one image of the window will be practically black. In paler stones the dichroism is not so marked, though still distinct. It is weakest in the pale green stones, almost like pale emerald in tint, which have been produced by heat-treatment of suitable material from South-West Africa.

Tourmaline is very seldom free from flaw-like liquid inclusions. Although these really consist of thin transparent films, in certain directions they give the effect of being black and opaque, due to total reflection of light at their surfaces. Typical inclusions of this kind are shown in the photomicrograph reproduced as Figure 78.

The absorption spectrum of tourmaline has been described in Chapter 8. It varies according to the colour of the specimen (as in other allochromatic minerals) and many varieties show no distinctive bands.

Before leaving tourmaline, one curious feature of the stone deserves mention. It is strongly 'pyro-electric'—which means that when undergoing a change of temperature opposite ends of the crystal become electrically charged in opposite senses. Pretty experiments can be carried out to display this effect, but the phenomenon makes itself known without any such devices when tourmaline jewellery is displayed in an illuminated window or display case and the stones are near enough to an electric bulb to become perceptibly warmed thereby. Under these conditions, tourmaline attracts to itself an amazing amount of dust, becoming completely coated if left for any length of time.

Although the question of their identification has been incidentally discussed in previous chapters, two other gem minerals, peridot and spinel, are sufficiently important to warrant specific mention.

Peridot is the name given in England to the green transparent variety of the important rock-forming mineral olivine, which is a silicate of magnesium and iron, termed 'chrysolite' in American mineralogy. The name 'olivine' has unfortunately gained wide currency in trade circles for quite another mineral, the green demantoid garnet from the Urals. Since the name olivine has been established for the magnesium-iron silicate for some 150 years there can be no question of its abandonment now. Thus, to prevent confusion, jewellers should avoid this name altogether, calling the green garnet 'demantoid' and using 'peridot' as a safe appellation for the true olivine.

Peridot is one of the easiest of all stones to recognize, both on account of its distinctive yellowish-green colour and because its strong double refraction gives a clear 'doubling' effect of the back facet edges when viewed through the table with a lens. So far as colour goes, the only close match is provided by paste imitations, and these, of course, are easily distinguished by their single refraction, not to mention their other physical characters.

Recently, synthetic corundum rather similar in colour to peridot has been produced, but when compared with the actual gem, the colour is distinctly different.

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Peridot is a mid-way representative of an isomorphous series of minerals of which the end-members are a magnesium silicate (forsterite) and an iron silicate (fayalite). The density and refractive indices of the mineral naturally vary according to the proportion of iron to magnesium present. The green types most commonly used in jewellery (from the Red Sea, Burma, Ceylon, or Arizona), all contain much the same amount of iron (about 10 per cent), and their properties do not vary greatly from 3·34 for specific gravity, 1·67 for mean refractive index and 0·036 for birefringence.

The Island of St. John in the Red Sea is the classic source for peridot and most of the stones used in jewellery originally came from there. Burma can also provide stones of fine colour and important size. Those from Ceylon are a darker, less pleasing green, and are often distinguished by curious disk-like inclusions resembling water-lily leaves. Small stones found on the Hawaii beaches have a beautiful colour and contain a trace of chromium. Hawaii peridot has the most curious inclusions for a natural stone. Being almost spherical and in heavy relief they bear a close resemblance to the bubbles seen in glass. Sometimes these 'bubbles' are oriented parallel to the outline of former crystal faces.

Peridots from all these sources have very similar constants, and all show a distinctive absorption spectrum in which three evenly-spaced bands are seen in the blue region.

For many years brown or yellow stones now known to be **sinhalite** were accepted as a form of peridot in which the higher refractive indices and density were thought to be due to a higher proportion of iron. Though structurally similar to peridot, sinhalite actually has an entirely different composition, being a magnesium aluminium borate. The properties of sinhalite have been described in Chapter 17. Peridots of brownish tint are in fact sometimes seen, but these have constants very similar to their green brethren, and confusion with sinhalite should not be possible when careful measurements of refractive index or density can be obtained.

Spinel also belongs to an isomorphous group of minerals, but the stones used as gems are mostly almost pure magnesium aluminates in which traces of chromic oxide and ferrous oxide produce red and blue colorations respectively. More common than

pure colours are less attractive intermediate shades to which it would be hard to give a name. Absolutely colourless spinel is practically unknown in nature, though stones of very pale mauve or pink are sometimes encountered. The means of distinguishing red spinel from ruby and from pyrope garnet have already been

Figure 79. Curious ghost-like 'feather' in red spinel from Burma

sufficiently described in Chapters 10 and 14. Under the microscope, spinel can usually be recognized by means of its typical octahedral inclusions. An interesting ghost-like 'feather' consisting of thousands of such small crystals is shown in Figure 79; this structure was found in a red spinel from Burma. Blue spinel is often very similar in appearance to indicolite tourmaline. Occasionally, blue spinels from Ceylon are found in which there is substantial replacement of magnesium by zinc, and the density and refractive index of such specimens are considerably higher

than normal. Pure spinel has S.G. 3·58 and R.I. 1·715, while the highest figures yet measured for a zinc-rich 'gahnospinel' have been 3·98 and 1·747. There is nothing in the appearance of these zinc-rich spinels to distinguish them from the normal types.

The most valued **spinels** are those approaching ruby-red in colour. In actual fact the colour, though attractive, never quite attains the rich crimson of ruby. This is luckily very noticeable under the microscope when testing parcels of small rubies, and this fact, together with the lack of dichroism and difference in inclusions are also signs which save the practised gemmologist from making a mistake when a spinel 'intruder' makes its appearance.

An excellent test for any pink or red spinel is to illuminate the stone with an intense beam of light which is concentrated on to the specimen through a flask of strong copper sulphate solution, and examine its fluorescence spectrum through a small prism spectroscope. The 'organ-pipe' group of bright red lines seen in the spinel spectrum is completely distinctive. Garnet will, of course, show no fluorescence of any kind, while with ruby the fluorescence is concentrated almost entirely into the fluorescence doublet which, in a small prism spectroscope, appears as a single strong bright line. It should be noted, however, that **synthetic red spinels** show a fluorescence spectrum which to the eye resembles that of ruby, though the main line is at 6840 Å instead of 6935 Å. It is not quite clear how or why these synthetics are being made. Spinel boules, if they are to grow well under the Verneuil blow-pipe should have a considerable excess of alumina compared with the 1 : 1 ratio of Mg : Al which is found in nature.

And with boules of the usual 1 MgO : $3\frac{1}{2}$ Al$_2$O$_3$ formula the effect of adding chromium to the raw materials is to produce a green colour, not red. It would scarcely seem worth while to take the special precautions necessary to grow red spinel boules of the 1 : 1 formula considering the small demand for natural red spinel compared with ruby. However, some stones of this type *have* been produced, and one must keep a watchful eye open for them. Curved lines and bubbles can be seen in the majority of these stones, very similar to those in synthetic ruby. A dark purplish-red synthetic recently seen did not show curved striae, but contained numerous comma- and tube-like gas inclusions, typical of synthetic spinel. Owing to their lower alumina content, these red synthetics have

a refractive index of only 1·715 compared with the 1·727 one usually associates with synthetic spinel.

Blue synthetic spinel is very extensively manufactured, particularly in pale shades which imitate aquamarine rather effectively. Their orange colour when viewed through the Chelsea colour-filter, cobalt absorption spectrum, and typical anomalous birefringence, giving a 'tabby extinction' effect between crossed Polaroids are all diagnostic.

Synthetic spinels also have a marked cubic cleavage, not seen in the natural stones, and this may manifest itself as cracks crossing one another at right-angles in carelessly cut stones.

Natural blue spinels are seldom really blue in the sense that sapphire is blue; they tend to be greyish, greenish, or inky-blue. Through the Chelsea filter they do show a reddish tinge, but this is far removed from the striking orange hue seen with synthetic blue spinels. The colour of blue spinel is due to ferrous iron, and this gives rise to a series of absorption bands. The key features are a broad absorption band in the blue, centred at 4590 Å with a narrow band on the green side of this, at 4800 Å. Weaker bands in the yellow and green are variable in intensity and position, but give the general impression of a rich and complex spectrum which is characteristic enough to be recognized by the practised gemmologist.

This 'blue spinel' spectrum is seen to some extent in the purplish types to which no exact colour description can be given. Such stones are lacking in beauty, and have small commercial importance. Spinel is one of the harder gemstones, being placed equal with topaz, the standard 8 on Mohs' scale. It takes a good polish, and in its pale varieties displays distinctly more fire than the corundum gems, though the numerical difference in this property is quite slight (0·020 for spinel; 0·018 for sapphire). In synthetic colourless spinel the 'fire' is quite perceptible: one of the factors which make it a popular substitute for diamond in cheap jewellery.

JADE AND JADE-LIKE MINERALS

ALL the stones so far considered are transparent, and their beauty largely depends upon that factor. Certain minerals, however, of which jade, turquoise, and lapis lazuli are the chief, have a sufficiently beautiful colour and are sufficiently rare to earn a place in jewellery despite the fact that they are translucent or opaque. The true jades and the many 'greenstones' which have passed as jade will be the subject of the present chapter, while turquoise and lapis lazuli will be dealt with in the chapter following.

Jade is a term which even mineralogists consider permissible for two distinct minerals. Of these, jadeite or 'Chinese' jade, is the rarer and more precious, though nephrite or 'New Zealand' jade has also been greatly favoured as a material for carvings by the Chinese, by whom the jade minerals are held in particularly high esteem. Jadeite is a silicate of sodium and aluminium and belongs to the important pyroxene group of rock-forming minerals, while nephrite is a silicate of calcium, magnesium, and iron, and belongs to the equally important amphibole group. The minerals owe their extreme toughness, which is one of their outstanding characteristics, to the fact that they consist of a mass of small crystal fibres or grains. A number of other compact green minerals have been used in place of jade, though chiefly for carvings, small bowls, bead necklaces, etc., rather than in actual pieces of jewellery. The properties of these materials will also be briefly noted here, to assist the reader to distinguish them from the true jade minerals.

Jadeite, owing to its beautiful colouring and texture, is in great demand for use in rings, brooches, pendants, ear-rings, necklaces, and so on, and fine translucent green pieces command high prices. Though bright green is the most favoured colour, jadeite is also found in a wide variety of hues, including black, white, mauve, orange, and brown. The colour of green jadeite varies greatly in saturation, from palest shades down to a deep emerald hue. The colour is often mottled, and veins or small patches of bright green in pleasing contrast to a background of almost pure white jadeite

are fairly common, and highly characteristic of the material. The texture of the stone is more granular than fibrous, and slight differences in the hardness of the constituent grains cause it to possess a peculiar dimpled or shagreened surface when polished—an effect which seems only to add to the charm of its appearance. In some pieces a bladed, gently shining, crystalline texture is plainly visible to the naked eye, or under a pocket lens. The better qualities of jadeite are appreciably translucent, and owe their bright green colour to chromic oxide. Such jadeite has an absorption spectrum rather similar to that of emerald, though the narrow bands in the red are not so clearly defined and are in rather different positions. It may be added that green jadeite, unlike emerald, does not show red under the Chelsea filter. In addition, as described in Chapter 8, jadeite often shows distinctive absorption bands in the violet, and these may be very valuable in confirming its identity. By far the stronger of these is at 4370 Å, and is a strong and very well-defined narrow band. In the paler varieties of jadeite it can be clearly seen by reflected light—or by transmitted light if the piece is thin and translucent enough to let through sufficient light. In brown or dark green pieces there may be too much general absorption in the region for the band to be visible. The density of jadeite of all colours is remarkably constant, and is almost exactly the same as that of methylene iodide (3·33), so that a trial in this liquid will act as a useful check where its characteristic appearance is not sufficient to establish its identity. In the case of the jade minerals, refractometer measurements cannot always be relied upon as a means of distinction, as stones are usually cut with rounded or carved surfaces. Where the back of a cabochon piece is sufficiently flat and polished, a fairly good reading can be obtained, and jadeite often shows the two edges due to double refraction, which is rather surprising in a crystal aggregate. The refractive indices are 1·654 and 1·667, and the hardness nearly 7 on Mohs' scale.

The distant vision method can usefully be employed to obtain an approximate refractive index reading on polished cabochon surfaces of jadeite, and provides a valuable confirmatory test.

Jadeite has a comparatively low melting point (lower than nephrite) and a splinter fuses easily to blebs of colourless glass under the blowpipe.

Although jadeite has been found in Japan, California, and

Gautemala, and the presence of celts of jadeite which were left in various parts of Europe by Neolithic man argues the presence of other localities for the mineral, there is only one source for the varieties of jadeite used in modern jewellery, and for carvings and *objets d'art*. This is in Upper Burma, in the neighbourhood of Myitkyina, where jadeite occurs in dykes of igneous rock and is recovered in boulders from the local streams. A coarse-textured dark green jadeite often known as 'Yunnan' jade probably also emanates from Upper Burma. The trade is entirely in Chinese hands, hence the popular name 'Chinese jade' for the material.

In actual fact the Chinese made no use of jadeite until the eighteenth century, all their ancient jade carvings being executed in **nephrite**, to which the Chinese, who venerated the material, gave the name Yu, which is also their name for precious stones in general. The name fei-ts'ui, 'king fisher stone', is now used by the Chinese for jadeite only, though originally given to certain fine green nephrites.

The Chinese sources for nephrite were chiefly in East Turkestan (Khotan, Yarkand), from whence boulders of the amphibole jade have been transported for centuries over an incredibly arduous trans-continental route.

New Zealand 'greenstone' is a rather unsatisfactory name often used for the true nephrite jade originally used and worked by the Maori from boulders found in the rivers Arahura and Teremelau in the South Island. Modern carvings in New Zealand nephrite are mostly carried out in Idar-Oberstein, where skilled craftsmen copy the Maori 'Tikis' and other designs. The stone has a fine spinach-green colour and contains rather more iron than do the Chinese varieties of the same mineral.

Mineralogically speaking, nephrite can be equated, according to its iron content either with tremolite, which is white in colour ('mutton-fat jade') or with the green mineral actinolite, which contains appreciable iron and supplies some of the asbestos of commerce. Both these minerals belong to the amphibole group, of which hornblende is the most important rock-forming member.

Other well known sources for nephrite are in the Lake Baikal region of Siberia, where gigantic boulders are found, and Jordansmühl in Silesia. Siberian nephrite is a translucent spinach-green containing black spots of magnetite or graphite, while the Jordansmühl material has an attractive range of colour from ivory white

to a fine translucent green, most specimens being markedly mottled.

The density of nephrite is markedly lower than that of jadeite, an average figure being 2·95, and the range being between 2·90 and 3·03. The refractive index is also lower, giving a shadow-edge near 1·62 on the refractometer. The hardness can be given as $6\frac{1}{2}$ on Mohs' scale, though the surface hardness of some old specimens seems higher, and other specimens may give anomalously low results; being easily marked by the point of a pocket-knife or needle. Nephrite is more fibrous than jadeite, and polished pieces lack the dimpled surface lustre of the latter.

Though so far only white ('mutton fat') and sombre green have been mentioned as colours for nephrite jade, shades of brown or yellow are sometimes seen, particularly in ancient, weathered pieces. The green colour is mainly due to ferrous oxide, which is an essential constituent; but the more richly coloured pieces may also contain a little chromium, and rather vague narrow bands in the red can be detected in consequence, though they are never so clearly developed as in jadeite. A weak line at 4980 Å where the green changes over to blue can sometimes be seen, perhaps accompanied by even weaker lines nearby, but there is no absorption band in the violet beyond a general absorption of the whole region.

Before proceeding to describe the many minerals which have been or may be confused with either of the two jades, warning must now be given of a new advance in the gentle art of faking. Methods have been developed for dyeing pale specimens of true jadeite so that they have the appearance of valuable green jadeite of the highest quality. According to information received from Hong-Kong, two organic dyestuffs, one blue and the other yellow, are used to obtain the desired effect. In some samples the colour can be seen, on close inspection, to be concentrated in the small cracks or veins in the mineral. But in others the colouring is surprisingly uniform, as though the dyestuffs had been able to penetrate the tiny crystals themselves.

The other form of colour-faking for jadeite is more elaborate, and involves careful workmanship, but so far as appearance goes the result is outstandingly effective. Here a piece of pale jadeite is hollowed out to form a thin-walled cabochon shell. A second piece of similar material is made to fit this exactly, and the two

are cemented together with a layer of green dyestuff between the two. In the specimens seen, no attempt has been made to conceal the fact that the whole is a composite stone, since a ridge can clearly be seen running round the base of the cabochon. But in mounted pieces this would not be detected, and high prices might very well be paid in error for stones which quite clearly show the characteristic texture and lustre of true jadeite and have a very fine green colour.

Fortunately there are tests which can reveal the fakes once suspicion has been aroused. In the first place, the dyed stones tend to show red or pinkish under the Chelsea filter, which natural green jadeite does not. In the second place, the spectroscope reveals the presence of dyestuff by means of a fairly strong though rather wooly absorption band in the red, while the narrow chromium lines which untreated jadeite of this colour would show, are missing. Stories of dyed mauve jadeite have recently come from America, and it is a regrettable fact that all finely-coloured pieces of jadeite must now be viewed with suspicion and preferably submitted to a laboratory test before good money is paid for such articles.

The colour of these stained jades can be removed by treatment with nitric acid or by less drastic reagents, but such a test is not a very satisfactory means of learning the truth.

Of the other jade-like minerals, the only ones likely to be seen in rings or brooches, and which might be mistaken for jadeite, are genuine **chrysoprase**, green **stained chalcedony**, and the green zinc carbonate, **smithsonite**, which is sometimes sold under the trade name 'Bonamite'. A density test may be relied upon to distinguish these and most of the other minerals which may be confused with either of the jades, or with each other, provided the specimen can be obtained free from its setting.

With mounted stones, refractive index reading by the 'distant vision' method will segregate the chrysoprase and chalcedony, while the smithsonite will effervesce when touched by a drop of dilute hydrochloric acid. It is worth remembering that all carbonates 'fizz' when touched with a spot of acid, owing to liberation of gaseous carbon dioxide. The test is a useful one for many of the ornamental stones, but obviously, as with hardness tests, must be used with care and discretion. A very small drop of quite dilute acid will suffice, and a lens used to verify that effervescence is

actually taking place. The drop of acid should be removed as quickly as possible: it will inevitably leave a dull mark on a polished stone.

Probably a safer manner of carrying out the test is to take a minute scraping of powder from the specimen, place this on a microscope slide, and to this add a small drop of dilute acid by means of a thin glass rod. The reaction can then be clearly observed under a low-power microscope.

This test for carbonates is only mentioned here on account of its extreme simplicity and frequent usefulness. There are many other chemical tests which can successfully be employed on the micro scale when dealing with the non-transparent gemstones. Some of these are described in Webster's *Gemmologist's Compendium*.

Many other massive green or greenish minerals have occasionally been used for beads, carvings, and small ornaments: the term 'jade', with some suitable or unsuitable sobriquet, is often misleadingly applied to these. Thus 'Transvaal jade' is a massive green form of **grossular garnet**, better known in jewellery in its orange-brown form of hessonite. This Transvaal grossular can be distinguished from true jades by its higher refractive index (1·73) and density (3·49); also by the small black spots which it frequently contains. This form of grossular also has a revealing orange fluorescence under X-rays. The pale apple-green form of serpentine known as **bowenite** makes an attractive substitute for jade, and was wrongly identified as nephrite by the Dr Bowen whose name it commemorates. This is curiously harder than other forms of serpentine, and also more translucent. The density of those specimens examined by the author and his colleague Mr Robert Webster have been consistently near 2·59, with refractive index 1·55; but higher values have been recorded in the literature, presumably for specimens from different localities. Little groups or chains of greenish flakes of chlorite are often enclosed in bowenite, and are a helpful characteristic in the recognition of this very pleasing material. The Maoris gave to the exceptionally translucent variety of bowenite found in Milford Sound the poetic name 'Tangiwai', meaning 'tears'. Quite large pieces are found in China and carved into imposing figures, plates, cups, and so on. A much softer green mineral sold as 'Styrian jade' is more properly called **pseudophite** or clinochlore, and belongs to the chlorite family, which is closely related to the serpentines. While

bowenite can just be scratched with a penknife, pseudophite is soften than even calcite.

Prehnite is another jade-like mineral, having a rather oily pale yellowish green and a radiating fibrous structure which is rather distinctive. It is highly translucent; in rare cases, indeed, it is quite transparent and colourless. One such specimen is in the author's collection, having been rescued from a junk-box by Mr Webster. **Amazon stone** is not unlike jadeite, though its bluish green

Properties of Jade and Similar Materials

Species	S.G.	Mean R.I.	H.
Jadeite ('Chinese' jade)	3·33	1·66	7
Nephrite ('New Zealand' jade) ...	3·00	1·62	6½
Pseudophite ('Styrian jade')	2·7	1·57	2½
Grossular ('Transvaal jade')	3·48	1·73	6½
Prehnite...	2·87	1·63	6
Bowenite	2·6	1·55	5½
Aventurine quartz ('Indian jade') ...	2·66	1·55	7
Chalcedony ('Swiss jade')	2·60	1·54	7
Amazon stone ('Amazon jade') ...	2·56	1·53	6
Californite	3·40	1·72	5½
Smithsonite ('Bonamite')	4·35	1·62*	5
Agalmatolite ('figure-stone')	2·80	—	2½
Saussurite	3·2	1·70	6½
Emerald	2·7	1·57	7½
Fluorspar	3·18	1·43	4

* The second refractive index is 1·849, but a vague shadow-edge at 1·62 is all that can be seen on the refractometer.

colour and typical feldspar sheen are easily recognizable to the practised eye. The massive green idocrase, **californite**, has been used as jade, and so has the impure secondary mineral **saussurite**. The green **aventurine quartz** has been called 'Indian jade', though its spangles of fuchsite mica render it easily distinguishable.

A type of aventurine quartz in which the spangles are not visible is sometimes encountered and might well be mistaken for malachite as it has a rather similar tone of green with bands of darker and paler colour. Its density, refractive index, and hardness, however, are those of quartz (aventurine, as Robert Webster

has shown, is really a **quartzite** containing chrome mica); moreover, it shows red under the Chelsea filter and a chromium absorption spectrum, with a doublet in the deep red near 6800 Å.

One more name should be mentioned. The mottled green material known as **verd-antique** is a serpentine marble. Its mottled and veined appearance, its effervescence when touched with acid, and a strong absorption band in the blue at 4650 Å serve to identify this rather attractive rock (one can hardly call it a mineral).

Connemara marble, Iona stone, and **ophicalcite** are all names which have been used, according to its occurrence or the taste of its user, for this same material. **Verdite**, which is a not very attractive dark green material composed of clay heavily impregnated with chrome mica, should not be confused with the verd-antique mentioned above. Its extreme softness (3) as well as its appearance should make any confusion with jade unlikely. Verdite has a density near 2·9 and refractive index 1·58.

Before closing the list of minerals which can be reasonably confused with jadeite or nephrite, one should mention translucent forms of **emerald**, and also **fluorspar**. Both these attractive materials have been used for small carvings in the manner of jadeite, and have a rather similar colour. A density test, or trial on the refractometer, may not be feasible. The emerald will show dichroism, and appear dim red between crossed filters, while both it and fluorspar will probably show pink under the Chelsea filter. Fluorspar is much softer than jade, it has a marked violet fluorescence under ultra-violet light and an easy octahedral cleavage which may manifest itself in any surface chips or as incipient cleavage cracks. **Imitation jade** made of glass may be very crude or quite effective. Scrutiny with a lens will reveal bubbles at or near the surface.

Long though it is, the above catalogue of minerals resembling jade could be considerably extended. The physical properties of the materials mentioned will be found summarized in tabular form for convenience, though it must be realized that these minerals, unlike transparent gemstones, are seldom pure, and therefore these properties may vary considerably.

The jeweller must not feel too appalled by the number of minerals mentioned. Few of them are actually used in articles of jewellery, and the main question, 'is it true jade or not'? can

usually be answered either by inspection or after a few simple tests. In confirming the identity of jadeite the spectroscope can be very helpful, since it can be used no matter what form the specimen takes, and is effective for mounted stones as well as unmounted. As has already been stated in Chapter 8, green jadeite shows well marked chromium bands in the red. These are narrow but unlike those in emerald (which they otherwise somewhat resemble) in being rather diffuse. Paler types of jadeite show a strong, narrow band in the violet at 4370 Å. This is present in green types also, but may be masked by the general absorption of the violet. If the specimen is sufficiently thin and translucent these bands are ideally seen by transmitted light, but can also be observed by strong reflected light, with the slit of the spectroscope held close to the brightly illuminated specimen. A flask of copper sulphate solution will make observations easier by concentrating the light and removing the glare from the unwanted end of the spectrum.

If it is desired to identify one of the less easily recognizable jade substitutes, it will be wiser to have it tested in a well-equipped laboratory or mineralogical museum having facilities for X-ray analysis.

It is of great assistance to have small samples of the various jade-like materials (most of which can be procured from a good mineral dealer) which will give the reader a better idea of their appearance and reactions to various tests than can be gained from written descriptions. A good idea of the appearance of jadeite, nephrite, and some of the minerals which resemble them closely can be obtained from the coloured frontispiece to this book.

TURQUOISE AND LAPIS LAZULI

TURQUOISE is a hydrous phosphate of aluminium and copper, in which some of the aluminium is usually replaced by iron. The sky-blue colour to which the gem chiefly owes its attraction is due to a copper compound, while iron when present tends to impart a far less desirable greenish tint. For practical purposes turquoise is amorphous, though small triclinic crystals of the mineral have been found. In thin section it is seen under the microscope to consist of crystalline particles, interspersed with amorphous whitish material. Specimens containing much amorphous matter are more porous, less dense, paler in colour, and softer than purer types. The density of the mineral acts as a rough guide to the quality of the material, if one discounts the brown limonite matrix which is frequently present in veins and patches. The density of limonite is about 3·8, so this would tend to raise the density of turquoise. Turquoise from the Sinai Peninsula ('Egyptian' turquoise) of fine blue colour and markedly translucent, has the highest density of any pure turquoise and it departs remarkably little from the value 2·81. Persian turquoise, which is even more highly prized, has a density only slightly lower, near 2·79. Neither of these varieties is appreciably porous and their hardness is about 6 on Mohs' scale. Turquoise in much larger pieces and of quite fair quality, comes reputedly from China in the form of snuff bottles, carved pieces and large cabochons, often veined with dark brown matrix. Such pieces have an average density of 2·72, and are also not very porous. Specimens from Nevada, Colorado, and other North American sources are decidely paler and more porous. In some cases a gain of as much as 2½ per cent in weight may result after soaking in water. The density is between 2·6 and 2·7. In carrying out determinations on these porous stones it is wiser to use the hydrostatic method, as pure water is less likely to harm their colour than immersion in heavy liquids. Nevertheless, a clean bromoform mixture should do no harm to Persian or Egyptian types, and provides a quick and useful test if the liquid is matched with a small known specimen from either locality, used as an indicator.

With mounted stones, a refractive index test is useful. Usually

only a cabochon surface is available, and turquoise is nearly opaque, but by using the 'distant vision' technique quite clear readings can be obtained on the refractometer, the shadow-edge being at about 1·62 or 1·63. Examination of the surface of the stone under the microscope is useful, particularly when specimens of genuine turquoise are available for comparison. Persian turquoise shows characteristic small patches and veins of whitish material, while Egyptian stones show small circular disks of deeper blue. Veins of the brown limonite matrix, when present, are a sign of genuine turquoise, though it is well to examine these too under the microscope to ensure that they are not 'faked'.

A useful distinctive feature of genuine turquoise from all localities, though unfortunately difficult to observe, is the presence of two strong absorption bands in the violet at 4300 and 4200 Å. The former of these can usually be detected in a small prism spectroscope when a powerful beam of light is transmitted through a thin edge of the stone or is reflected from its surface. None of the materials resembling turquoise show this band. A weaker band in the blue is also usually present in turquoise but it is generally more feasible to view it by reflected light. Here a flask of copper sulphate solution makes a useful condensing lens, as it not only concentrates the light on to the specimen, but filters out the red and yellow end of the spectrum, making bands in the blue and violet easier to observe.

Imitation turquoise has been made from suitably coloured plaster of Paris, and from various secret mixtures, some of which are said to have a similar composition to that of turquoise itself. All those encountered by the author have been softer, more porous, and of lower density than true turquoise, and they lack its typical surface structure. **Glass imitations**, which are not uncommon, will show small bubbles under the surface, and so also will **porcelain**; while **enamel** and **stained chalcedony** show none of the typical veining of the true turquoise. To the practised eye, the vitreous lustre of these imitations is visibly different from the slightly waxy lustre of turquoise.

Of the natural minerals resembling turquoise, **odontolite** or 'bone turquoise' is a fossil ivory or bone which has become stained blue by the iron phosphate mineral vivianite. Odontolite invariably contains some calcium carbonate and thus effervesces when a drop of dilute hydrochloric acid is applied to it. Odontolite can

be distinguished both by its higher specific gravity of 3·00 to 3·25, and its organic structure when examined under the microscope. The hardness is about 5 on Mohs' scale. **Variscite** is a green hydrous aluminium phosphate, hardness 5, and specific gravity near 2·5. The mean R.I. is also lower than that of turquoise, being about 1·58. **Amazon stone** feldspar, already mentioned under jade, may also be mistaken for turquoise of poor quality, but again, its lower density and refractive index will serve to separate the two. The mineral **lazulite** (not to be confused with lapis lazuli) is not often seen in jewellery, but should be mentioned here, as it sometimes closely resembles an inferior turquoise. It is rather more translucent, has a very similar refractive index, but a higher density (3·1). Under the microscope it lacks the surface structures of turquoise mentioned on the previous page.

With practice the narrow 4300 band in the violet and its weaker and broader associate at 4600 Å in the blue can always be seen in true turquoise, and its presence is, in the author's experience, conclusive evidence of the authenticity of a specimen. The appearance of the surface under the microscope and a distant vision refractive index reading also provide useful evidence.

It must be recognized that the surface of almost all poor quality turquoise is 'improved' to a greater or lesser extent by treatment with copper stearate or other wax-like or plastic substances. In some cases this treatment affects the colour of the stone to a depth of several millimetres. It is difficult to decide where legitimate improvement ends and fraud sets in.

It must frankly be admitted that turquoise is a difficult material to test, particularly when mounted and of poor quality. The jeweller, when in doubt, should pass it on for a laboratory test. As a last resort, an X-ray powder photograph provides conclusive evidence.

LAPIS LAZULI

The use of **lapis lazuli** as a stone for adornment goes back to very early times, and the ancient mines in Afghanistan are still providing the finest material after being worked more or less continuously for some 6000 years. Almost alone among gem materials, lapis lazuli is not a single mineral but a *rock* in which blue minerals such as lazurite, haüyne, and sodalite are inextricably mingled with calcite, diopside, pyrites, and other species. In fine specimens

the blue minerals sufficiently predominate to give an almost homogeneous appearance to the polished stone, though brassy specks of pyrites are almost always to be detected, and form a useful sign that the stone is genuine. Poorer quality material such as that from Chile contains considerable white areas, and even the blue regions are diluted to a paler tint than the true deep ultramarine.

The density of lapis lazuli has often been given in text-books as 2·38–2·45, but these figures are based on measurements originally carried out nearly 100 years ago on small fragments of the included blue minerals. The specific gravity of fine pieces of lapis actually averages about 2·80, and 2·7–2·9 may be taken as the normal range unless much pyrites is present to raise the density to higher values. True lapis may thus be distinguished from its commonest imitation, the stained jasper known as 'Swiss lapis', which has a density of only 2·58. This 'Swiss lapis' material should actually be distinguishable at sight, since its colour is an inferior blue, it has a more vitreous lustre, and contains little patches or veins of transparent quartz in contradistinction to the brassy specks of pyrites seen in genuine lapis lazuli.

In 1954 a new and effective imitation of lapis lazuli appeared. This was a form of synthetic spinel coloured heavily with cobalt, which was manufactured by heating the ingredients (oxides of magnesium, aluminium and cobalt) at temperatures rather below the 2130° C at which spinel actually melts. The result is a granular crystalline product, formed in the solid state, that is, 'sintered', and **synthetic sintered spinel** is a correct description of this new imitation of lapis—though some easier nickname will probably eventually be adopted for it by the trade. Dr Jaeger was the inventor of this process, and the stones are marketed by the firm Degussa in Frankfurt.

Specimens of this new sintered imitation lapis are rather expensive: they are sold as small flat ovals or rectangular tablets ready for use as seal-stones, for which their hardness, lustre, and fine colour are well adapted. If desired, small specks of gold can be inserted to simulate the brassy specks of pyrites which are known to be a characteristic feature of genuine lapis lazuli.

This new imitation is not difficult to recognize, since its structure and all its properties are different from those of the mineral it represents. Examination under a lens reveals a granular texture,

and under the Chelsea filter it appears a brilliant red (true lapis is a dull brownish red under the filter). Readings on the refractometer are not clear-cut, but a shadow-edge near 1·725 can be seen (lapis gives vague readings near 1·50). The hardness of the sintered spinel is 8 on Mohs' scale, and its density 3·52. By reflected light it shows a strong cobalt absorption spectrum, with bands at 6500 Å (strong) in the red, 5800 (weak) in the yellow, 5320 (strong) in the green, and 4800 and 4520 in the blue.

The material is only feebly translucent, showing a peculiar reddish-purple colour when a strong beam of light is transmitted through a thin piece.

Other imitations of lapis lazuli are unlikely to prove deceptive. One blatant fake is a blue aventurine glass, spangled with triangular crystals of copper.

Two other blue non-transparent minerals which are sometimes cut and polished should be mentioned here. One of these, **sodalite**, belongs to the same group of minerals as the blue material in lapis lazuli, and has rather a similar appearance, though the colour of sodalite is bluer and less saturated than that of fine lapis. The hardness of sodalite (6) is the same as that of lapis, but the density is distinctly lower, 2·30 being an average value. The refractive index (1·48) is also rather lower, but good readings are not easy to obtain.

The other mineral, **lazulite**, has already been mentioned under the minerals which might be confused with turquoise, which it resembles much more closely. It is the similarity in name that makes it seem worth bringing into the present context. The name 'lazurite' has often been used by mineralogists to represent lapis lazuli, or the blue content of the stone, and this is simply asking for trouble, since a real feat of memory is needed to remember that the '-lite' mineral is something quite different from lapis. Perhaps an easier mnemonic is to remember that the '-rite' mineral name is the 'right' one in this instance.

CAT'S-EYES, STAR-STONES, AND OTHERS

Gems which owe their attraction to special optical effects can now be considered. Minerals which contain thin crystalline rods or fibres, in parallel formation, or canals where these have formerly been, are found to display a band of light at right-angles to the direction of the inclusions when they are cut *en cabochon*. This is due to reflection from the surface of the thin crystals, and the result is popularly known as a 'cat's-eye', the general name for the phenomenon being 'chatoyancy'. The more numerous and the finer the inclusions, the more perfect is the resulting ray. The **cat's-eyes** most frequently seen are those of **chrysoberyl** and **quartz**. Of these, chrysoberyl provides stones which have a more sharply-defined and slightly iridescent ray. It also takes a higher polish. When this is combined with a translucent body-colour of honey-yellow or greenish-brown the resulting stone can be one of the most lovely of all gems, and of considerable value. As with all cat's-eyes, the ray appears at its best under a single light or in direct sunlight. Multiple or diffused illumination spoils the effect.

Quartz cat's-eyes in their natural state are usually pale fawn or yellowish brown in colour. The structures producing the ray are not fine canals as in chrysoberyl, but fibres of asbestos, often too coarse to give a really silky ray. At their best, quartz cat's-eyes are very difficult to distinguish by sight from their more precious counterparts, while there are many inferior chrysoberyl cat's-eyes which present an untypical appearance. Where the stones are unmounted a quick and certain test is to place the stone in bromoform or methylene iodide, in either of which quartz will float and chrysoberyl rapidly sink. Where the stone is mounted, a refractive index reading by the 'distant vision' method will settle the issue with equal certainty, quartz giving a reading around 1·55, while with chrysoberyl the shadow edge will be near 1·75. Where enough light can be transmitted through the specimen, an absorption band in the blue-violet at 4450 Å will prove the stone to be a chrysoberyl. **Tourmaline, emerald**, and **chrome diopside** are among the species in which the chatoyancy effect is not

very uncommon, while very perfect cat's-eyes have been found in pale pink and deep blue or violet **scapolite** from Burma. These scapolites have S.G. near 2·61 and refractive indices 1·54–1·55; they are decidedly rare.

The handsome golden-brown chatoyant stone known as **'tiger's-eye'** quartz, or more commonly **'crocidolite'**, was originally a blue mineral of the amphibole group, in which the long fibrous crystals have been replaced by silica, and oxidation of the residual iron content caused a change to its present attractive colour. Crocidolite is really the name of the original unaltered mineral. The appearance of this stone with its golden and brown banded structure, make it easy to recognize at sight: its properties are similar to those of the other quartz minerals. A similar material, which has retained its blue colour, is found near Salzburg in Austria. Grey varieties, and paler types which have been stained in a number of unlikely colours, are sometimes seen in cheap jewellery. All these are apt to be included under the rather vague term **'Hungarian cat's-eyes'**. They are usually cut in long oval cabochons with very steep sides and a flat base. The ray is sharp and clear, but the stones are virtually opaque, and there is none of the subtle translucent background or living movement in the silvery ray that makes a fine chrysoberyl cat's-eye incomparable in its class.

Though not a mineral, and devoid of chatoyancy, what is sometimes called **shell** or **Chinese cat's-eye** should be mentioned here. This is one form of **operculum**—a domed piece of shell which serves as a lid to the door or orifice of a snail-like (gastropod) shell-fish. Those mostly used are from the species *Turbo petholatus*, which is found in the seas north of Australia as far as Indo-China. They are used in their natural form in brooches or bracelets, etc. The upper surface is domed, with a porcelain-like lustre and shades of colour grading through browns, yellows and greens. The base is flat and lacking in lustre, and shows spiral lines of growth. The density of operculum is 2·70 or a little higher, and the hardness about $3\frac{1}{2}$ on Mohs' scale.

Asterism, or the star-stone effect, is a phenomenon essentially similar to chatoyancy, the difference being that instead of a single shimmering band of internally reflected light, two, three, or even six such bands are seen, which by crossing produce four-, six-, or twelve-rayed stars.

The inclusions, oriented parallel to important symmetry directions of the mother crystal, can usually be seen under the microscope if the illumination is suitably arranged.

The most beautiful **star-stones** are those found in the corundum gems, **ruby and sapphire.** In these the star normally has six rays, intersecting at angles of 60°. The clearest stars are usually found in translucent sapphires of pale greyish blue, star rubies or sapphires of fine colour being extremely rare. The star is always displayed to its best advantage in direct sunlight, or under the light of a single bulb—and diffused daylight will show it at its worst. Very occasionally a twelve-pointed star may be seen in

Figure 80.   A twelve-pointed star sapphire

sapphire, the rays being alternately sharp and diffuse. One such stone, weighing 7·28 carats, and having a deep purplish colour, is in the author's possession. A photograph of this specimen, magnified five diameters, was taken by light reflected from a carbon arc and is reproduced in Figure 80. Formerly a corundum showing a star could with certainty be considered a natural stone. The new synthetic star rubies and sapphires referred to in Chapter 6 have altered this comfortable state of affairs, and it is now necessary to examine each star-stone critically to ensure that it shows the zoned structure of the native star corundums, and not the bubbles or curved colour bands of Verneuil synthetics. Other

stones to display asterism are **rose quartz** (six rays), and **almandine garnet**, which may show a series of faint four- and six-rayed stars. An ingenious form of doublet in which the brilliance of the rose quartz star is greatly enhanced has already been described in Chapter 18. The latest intruder into the star stone market has nothing natural about it. It consists of a cabochon of blue glass on the base of which fine lines, intersecting at 60°, have been scored. This is backed with a metallic mirror, as in the rose quartz doublet, and the star produced is remarkably effective. While these may be popular for costume jewellery, they can only deceive the unwary and the unforewarned.

The beautiful and unique sheen displayed by the feldspar known as **Moonstone** is also due to the internal structure of the
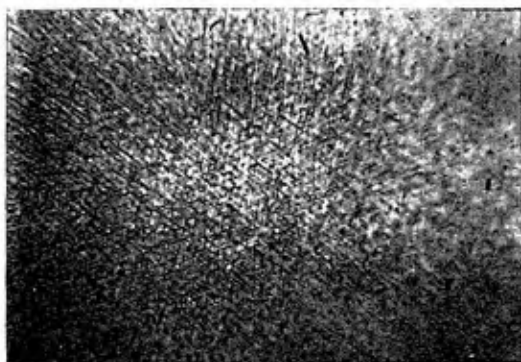
Figure 81. '*Silk*' *in synthetic star sapphire*

stone, which is, in fact, constructed of extremely thin layers of two sorts of feldspar, orthoclase and albite. Light is reflected from these layers in lovely elusive silvery gleams, which have a decided blue moonshine tint in the finest specimens, which come from Burma. No substitute can really imitate this effect; opalescent glass or milky quartz or white chalcedony could only deceive those who are unacquainted with the real thing. Ordinary moonstone has a density of 2·57, but '**black moonstone**' from Burma showing a similar effect though with more play of colour is a variety of **labradorite feldspar**, and has the higher density of 2·69. **Sunstone** or **aventurine feldspar** is a translucent, pale

brownish speckled and spangled material, seldom used in jewellery and having S.G. 2·64. For other aventurines, see p. 224.

The most effective substitute, perhaps, is a milky heat-treated form of white synthetic spinel which has recently been marketed. Heat-treated amethyst, milky white in colour, is also used in Idar-Oberstein as a cheap substitute for moonstone. A density test in suitably diluted bromoform will distinguish true moonstone from these inferior stones.

Brief mention may also be made of two opaque stones which are currently being used in cheap jewellery on account of their

Figure 82. *Zoned bands of 'silk' in natural star sapphire*

brilliant metallic lustre. These are **haematite** and **iron pyrites**, the latter being sold in the trade as '**marcasite**', which is the name properly belonging to another less common mineral of similar composition. Haematite is an oxide of iron, of which it is an important ore. It is mined, among other places, in Cumberland. When cut and polished, haematite displays a brilliant black metallic lustre, but its true colour is red, as can be seen when its powder is made to form a 'streak' by rubbing a specimen across an unglazed porcelain plate. The well known polishing agent, 'jeweller's rouge', is made from powdered haematite. Spheres of

haematite have occasionally been used to represent black pearls, but the resemblance between the brilliant metallic-looking surface of the mineral and the pearly lustre of the latter is very remote. The high density of haematite (4·95–5·16) and its red 'streak' serve as distinguishing factors if its appearance leaves any doubt in the mind of the observer.

The name 'Hemetine' is the trademark of a clever substitute for haematite manufactured in the U.S.A. Recent samples have a similar streak and density to the true material, but those seen by the author were strongly attracted by a pocket magnet, providing a rapid means of distinction from the natural mineral.

Iron pyrites or 'pyrite' is the commoner of the two crystallized forms of iron disulphide. The brassy colour of this mineral has frequently caused it to be mistaken by the ignorant for native gold. Seams and flakes of pyrites are often to be seen in household coal, where its presence in any quantity may cause minor explosions in the grate. Allusion has already been made earlier in this chapter to the specks of pyrites seen in most specimens of lapis lazuli. True **marcasite** is far less common, and is more liable to decompose than pyrite. Practically all 'marcasite' used in the trade to embellish inexpensive jewellery has been cut from crystals of pyrite. Its density is nearly the same as that of haematite: 4·9–5·1. The most plausible substitutes for 'marcasite' are brass and stainless steel, but the low cost of the real material makes any such deception hardly worth while.

To conclude this chapter, a short description may be given of some opaque or translucent ornamental stones which are occasionally used in jewellery.

The appearnace of **malachite**, with its handsome bandings and circular markings in dark and pale green, is familiar to most people. It is a hydrated carbonate of copper, with hardness only 4 and a density of near 3·8. **Azurite** is a dark blue copper carbonate containing rather less hydroxyl, and is sometimes interbanded with malachite in the same specimen. **Rhodochrosite** is a translucent pink carbonate of manganese, sometimes marketed under the trade name 'Rosinca', and used for clock cases and the like. It is difficult to distinguish from the manganese silicate **rhodonite**, though the latter is often characterized by black veins of manganese oxide. A hardness test here may be justified: the silicate has hardness 6 and the carbonate only 4. '**Mexican**

onyx' is a rather misleading name used for a translucent decorative marble, much used for clock-cases, ash-trays, and book-ends, etc. It is usually stained in shades of yellow, pink, or green.

All the above minerals except rhodonite, it may be noted, are carbonates, and it is worth remembering that as a subsidiary test they will all effervesce when touched with a drop of dilute hydrochloric acid. Inevitably a dull spot will show where such a test has been made, so that a safer procedure may be to scrape a trace of powder from an inconspicuous part of the specimen and carry out the acid test under the microscope on a glass slide.

AMBER, TORTOISESHELL, CORAL, AND JET

AMBER differs from most gem materials in being of vegetable origin. It is a fossil resin, originally exuded from coniferous trees some ten million years ago and still containing insects of the Eocene age trapped within it. Several types of amber are recognized, though their properties are practically identical; of these, Baltic amber, or 'succinite', is by far the most important. Baltic amber is always some shade of yellow, ranging from whitish to brownish yellow; it may be transparent, cloudy, or almost opaque owing to the inclusion of myriads of small air bubbles. Sicilian amber (simetite) and Rumanian amber (rumanite), are seldom yellow; shades of brown, reddish brown and even black being more common. Rumanian amber is often extensively cracked, but can none the less be turned and polished successfully. Burmese amber or burmite is generally brown. It contains many insects and sometimes veins in which calcite can be seen. Slight differences of composition are known to exist between these varieties of amber, all of which are essentially hydrocarbons. Succinite, as its name suggests, contains more succinic acid than the other ambers, giving rise to characteristic choking fumes when it is strongly heated. Gedanite is an amber-like fossil resin which is found with succinite. It contains no succinic acid and is soft enough to be scratched with the fingernail.

The hardness of the four main varieties of amber is from $2\frac{1}{2}$ to 3 on Mohs' scale, Burmese amber being the hardest type. The density ranges from $1 \cdot 04$ to $1 \cdot 10$; the presence of numerous air bubbles in cloudy amber makes its density slightly lower than that of clear specimens. Being amorphous, amber has only a single refractive index, which averages $1 \cdot 54$. It softens at about 180° C, melts between 250° and 300°, and burns with a characteristic aromatic odour. One of the best-known properties of amber is the ease with which it becomes electrified when briskly rubbed— attracting small pieces of paper or other light objects. In this respect several of its imitations behave in a similar manner, so that this cannot be regarded as a distinctive test, except that where *no* frictional electricity is developed (as seems to be the case

with the casein plastics described later) the material is certainly *not* amber.

First amongst the imitations of genuine block amber must be reckoned **pressed amber**, or **ambroid** as it is often called. Since the year 1881 this material has been extensively made from fragments of Baltic amber which are too small to be used as individual pieces. These are softened by heating to between 200° and 250° C and pressed through a fine steel sieve or mesh to become amalgamated into a coherent mass which has very much the same properties and appearance as block amber. The best method of detection is by examination under a lens or microscope, or simply with the naked eye. Pressed amber shows a flow structure, globules of clear amber amongst the cloudy mass following definite lines. There may also be elongation of included bubbles parallel to one direction, whereas in untreated amber bubbles are spherical. The more recent natural resin **copal** or **kauri gum**, which is extensively used in New Zealand, has very similar properties and appearance to amber. It can be distinguished by its readier fusibility when a hot needle is placed on some inconspicuous part of the specimen (comparison with amber will be necessary to make this difference noticeable) and by its greater solubility in ether. When a drop of this liquid is placed on copal resin it becomes quite sticky, and a dull spot is left on the surface when the liquid has evaporated. Amber is unaffected by this treatment, and so is pressed amber, despite statements to the contrary.

Amber is effectively and frequently imitated by various artificial resins which are generally grouped together under the inclusive term 'plastics'. The earliest of these, the cellulose nitrate known as **celluloid** is now less often used on account of its dangerous inflammability, though safety celluloid (cellulose acetate) bearing names such as **'Cellon'** and **'Rhodoid'** does not suffer from this disability. The casein plastics **'Galalith'**, **'Erinoid'**, etc., are more suitable, and most used of all are the phenol-formaldehyde condensation products **'Bakelite'** and **'Catalin'**. Some actual determinations on the density and refractive index of imitation amber and tortoiseshell made from these plastics materials are tabulated opposite, the properties of block amber, copal, and tortoiseshell being included for comparison. Further reference to tortoiseshell will be made later in this chapter. Owing to differences in the filling materials used to give body and

colour to these plastics, there may be some variations in their density and refractive index, but the figures given are sufficiently typical.

It will be noted that the specific gravity of all these materials, though low compared with gemstones, is considerably higher than that of amber, and this provides one of the most useful and reliable methods of distinction. It would of course be possible to

Properties of Amber, Tortoiseshell, and Plastics

Material	S.G.	R.I.	Under Knife
Amber	1·08	1·54	Splinters readily
Copal resin	1·06	1·53	Splinters readily
Tortoiseshell	1·29	1·55	Sectile
Galalith-imitation amber ...	1·33	1·54	Sectile, rather tough
Erinoid, imitation tortoiseshell	1·32	1·53	Sectile, rather tough
Erinoid, imitation tortoiseshell	1·34	1·54	Sectile, rather tough
Bakelite, imitation amber ...	1·28	1·64	Sectile, tough
Bakelite, imitation amber ...	1·26	1·66	Sectile, tough
Cellon-imitation tortoiseshell ...	1·26	1·48	Sectile
Rhodoid, imitation tortoiseshell	1·28	1·49	Sectile
Celluloid, imitation tortoiseshell	1·38	1·49	Readily sectile
Celluloid, imitation tortoiseshell	1·42	1·50	Readily sectile

dilute sufficiently one of the usual heavy liquids such as bromoform with toluene to make a solution of density about 1·12, suitable for separating amber from these imitations, but this would be both wasteful and unnecessary, since a strong solution of common salt will answer the purpose equally well. According to Mr Robert Webster, who has made a study of the subject, ten level teaspoonfuls of salt in an ordinary tumblerful of water provides a liquid of the required density. In this brine solution all specimens of amber, pressed amber, and copal resin will float, while all the usual plastic imitations will sink.

Two types of plastic not given in the above table, since they

have not yet been used to imitate amber, should perhaps be mentioned here. One of these, the remarkably transparent 'Perspex' or 'Diakon' is a polymerized acrylic ester, and has S.G. 1·18 and R.I. 1·50. Most of the modern 'ivory' and coloured telephones are moulded in Diakon. The other, a polystyrene product now made in this country under the name 'Distrene', has the very low density of 1·05, though its refractive index is comparatively high (about 1·58). Distrene would of course float in the brine solution together with amber and copal resin, but the fact that it peels under the knife, its much lower softening point (70–90° C), and its ready solubility in benzene, would enable it to be distinguished from amber if it should ever be used as an imitation.

In cases where it is not possible to obtain an unattached specimen for a density test, other tests are available. These, unfortunately, involve marking the specimen to a slight extent, but with care such damage is almost imperceptible when carried out on an inconspicuous part of the specimen such as the edge of the stringing hole of a bead. One such test, already implied in the table, is to determine the sectile qualities of the material by carefully controlled application of the sharp blade of a pocket-knife. It will be found that amber, pressed amber, and copal resin break away in chips or splinters under the blade, while plastic materials peel away in shavings. Bakelite is extremely tough and resistant to the knife; celluloid, Rhodoid, and Perspex yield much more readily, while Erinoid is intermediate in its toughness. The jeweller is advised to practise carrying out this test on known pieces of poor quality amber and on any plastics he can obtain before attempting to use it on specimens of possible value. Any peelings or chips removed can further be tested in the flame of a spirit lamp on the blade of a knife. Amber, pressed amber, and copal all burn with emission or aromatic fumes. Celluloid is extremely inflammable, but Bakelite and Erinoid only char under these conditions.

Glass imitations of amber are sometimes seen, and from a distance may look effective, but their coldness to the touch, hardness, and high density compared with amber all serve to avoid any real confusion.

Though it can hardly be described as a gem material, a few words on **tortoiseshell** may be useful here, as it is very extensively imitated by the plastics which have just been described.

The properties of the casein plastics and those of the safety celluloid type are very similar to those of true shell, as can be gathered from the table. Under the microscope, the dark patches of tortoiseshell will be seen to contain swarms of spherical reddish particles, whereas in the plastics the imitative dark patches lack this structure, and the edges of the dark areas are more sharply defined. Chips of tortoiseshell fuse to a black mass smelling of burning hair, while casein plastics char and smell of burnt milk.

Coral, like pearl, is a product of the sea. It is formed from the calcareous skeletons of myriads of tiny polyps which live in vast colonies in warm waters of moderate depth. Many forms of coral exist, but only the so-called noble or precious coral is at all extensively used for adornment. It is composed chiefly of calcium carbonate in the form of calcite, arranged as fibres radiating from the central axis of the curving coral branches. The specific gravity is about 2·68 and the hardness a little less than 4 on Mohs' scale. Red and pink are the most popular shades, and staining is sometimes resorted to for obtaining a desired tint. Imitations of coral have been made in galalith of suitable colours, but these can easily be distinguished by several tests. The density of coral is far higher, and it effervesces briskly when a small drop of hydrochloric acid is applied to the surface. The grained structure of coral is also distinctive, and this is of assistance in separating it from the **pink conch pearl**, which is of higher value. Pink pearl also has a higher density than coral (2·84) since its chief mineral constituent is aragonite in place of calcite. (See Chapter 24.)

Jet, like coal, is a form of fossilized wood. Its hardness is $3\frac{1}{2}$ on Mohs' scale, and its density about 1·30. Its former popularity as a material for mourning jewellery has dwindled practically to nothing in modern times. It can be distinguished from vulcanite imitations by the absence of sharp edges in the latter, which are moulded and not cut, and from black glass and black onyx by its lower hardness, lower density, and warmth to the touch.

PEARLS : REAL, CULTURED, AND IMITATION

THE pearl holds, and always must hold, a unique position amongst gems. In its long and illustrious history it has ever been highly prized for its silvery beauty, which needs no enhancement at the hands of the lapidary. While closely connected with the galaxy of precious stones, it stands apart from these by virtue of its origin within the living body of a mollusc.
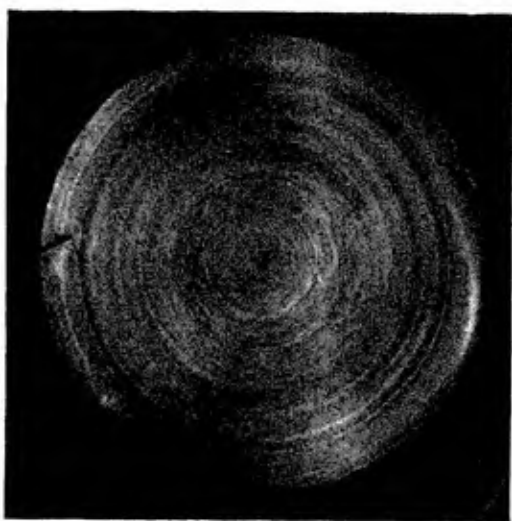
Figure 83. Section of oriental pearl, showing concentric structure

The structure of pearls is a consequence of their manner of growth within the pearl sac, which takes place in a very large number of successive stages. In each minutely thin layer, a delicate membranous network of cells is first formed from the horny material known as conchyolin, followed by the deposition of minute aragonite crystallites within each cell, much as honey is deposited in the waxen framework of hexagonal cells in a honeycomb. This organic framework is on so fine a scale in oriental pearls that it is invisible even under high magnification,

but it suffices to maintain the shape of the pearl after it has been completely 'demineralized' by treatment with acid, which removes all carbonate of lime from the framework. The above describes growth of one pearly film only, and there may be many thousands of these superimposed and overlapping in the completed pearl. How thin these layers are may be gauged by examining the surface of a pearl under the microscope. The surface is seen to be crossed with extremely fine irregular but roughly parallel lines, which are actually the edges of the fine layers of deposition. It is to the
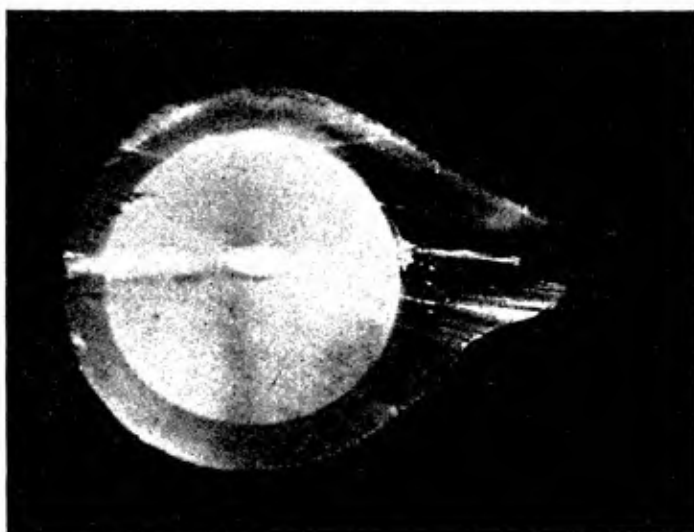
Figure 84. Cultured pearl drop, halved to show mother-of-pearl nucleus

combined effect of the superposition of these thin translucent plates and their closely spaced overlapping edges that the 'orient' of the pearl is due. Examination of even the finest imitation pearl shows a complete lack of this highly characteristic structure. The closer the spacing of the serrated plate edges, the finer the lustre of the pearl.

Apart from these small-scale discontinuities of growth there are the seasonal cessations from growth which give rise to the well known concentric layers which are easily visible to the naked eye in any sectioned pearl and can also be seen by looking down the drill hole of a pierced pearl with a lens. (Figure 83.)

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In **cultured pearls** the structure is entirely different. In place of the vanishingly small or entirely absent nucleus characteristic of the natural pearl, there is a mother-of-pearl bead in which the layered structure is flat or only slightly curved. The great difference between natural and cultured pearl structures can be seen in Figures 83 and 84. There have been rumours of small real pearl nuclei having been used, but all supposed specimens of this kind so far examined by the author have proved to have the usual mother-of-pearl bead as nucleus. Occasional use of glass bead nuclei and even nuclei of steatite has been reported.

The thickness of the pearly coating of the bead in cultured pearls varies considerably. In the cheaper varieties often a mere

Figure 85. Subcutaneous marking in cultured pearl

film has been deposited, enabling the observer to detect the tell-tale sheen reflected from the underlying bead, and to see the 'stripes' of the mother-of-pearl structure when the pearls are held against a bright source of light. The most usual thickness is perhaps half a millimetre, and the thickest skins may be rather more than two millimetres thick, showing as many as three layers —but these are very rare. Contrary to common belief, it is not necessarily the bead with the thickest skin which has the best appearance, always provided that sufficient thickness has been attained to hide the irregular sheen of the underlying mother-of-pearl. A cultured pearl drop, halved to show the interior structure

is shown in Figure 84. It can be seen that conchyolin deposited at one end of the bead formed the basis of the 'drop' shape.

To one who is accustomed to handling pearls, the difference in appearance and even the 'feel' of cultured pearls is usually quite sufficient to enable them to be distinguished in a moment from genuine pearls, especially when a number are seen together, as in a necklace. To put these minute differences into words is not easy, but the following points may be helpful to the beginner.

The colour of cultured pearls is often slightly greenish : artificial rose, cream, and deeper tints have sometimes been imparted by introduction of dye-stuffs into the drill-holes, where it may creep between nucleus and skin. This can usually be detected by examination with a lens, but in any case these faked pearls are not very common. The lustre of cultured pearls tends to be waxy, as the outer coating is more highly translucent than the substance of an oriental pearl—though Venezuelan real pearls are also notably translucent. The drill-holes of cultured pearls are generally larger than those of new oriental pearls, and are frequently crooked. Also, when a broacher is turned in the drill-hole, cultured pearls feel perceptibly softer than the natural.

Examination of the drill-hole with a good lens under a strong light shining on the side of the pearl will also help to distinguish between the two types. Cultured pearls have a sharp line of demarcation between bead and outer coating, forming a complete unbroken circle; the junction is not infrequently marked by a black line of conchyolin, deposited maybe by way of protest by the oyster before getting to work with the nacre. Below this line no further growth-lines can be seen, whereas in natural pearls there are a series of these, often getting more yellow or brown in tint as the centre of the pearl is approached. Where there is a black deposit of conchyolin at the *centre* of the pearl it is a sure sign that it is genuine.

When faced with a pearl necklace of doubtful origin, it is a good plan to undo the clasp, and to hold the string, fully extended, between the thumb and forefinger of either hand, rotating the beads slowly below a strong light. If the pearls are cultured, some at least will probably be found to reflect the tell-tale gleam of mother-of-pearl, as previously mentioned, when the correct angle is reached. Darkish subcutaneous markings, like varicose veins, are also typical of cultured pearls. One such marking is

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shown in the photograph (enlarged about 8 diameters) repro-
duced in Figure 85. The sharp line of demarcation between skin
and nucleus can also be seen.

So much for visual means of distinction. As to scientific tests,
various optical and X-ray methods have been evolved which give
a sure distinction in all cases, but these require expensive apparatus
and expert handling.

Thirty years' experience has confirmed the belief that for drilled
pearls the 'endoscope' provides the most reliable rapid test for
distinguishing between natural and cultured pearls. More than a
million pearls have been tested on this instrument in the London
Laboratory alone, and a similar number in Paris.

The endoscope was produced in Paris to a design by Chilowsky and
Perrin, and was modified a year later by the pearl dealers Simon
and Réné Bloch. The improved model was marketed in 1926, and
twenty-five of these instruments were imported into this country.

The essential part of this ingenious apparatus is a hollow needle,
small enough to enter the drill-hole of a pearl, into the end of
which is fitted a short metal rod, polished at either end to form
two tiny mirrors inclined, in opposite senses, at 45° to the length
of the needle. One of these mirrors forms the extreme end of the
needle, while opposite the other mirror there is a hole in the
needle through which light can pass. The accompanying diagram
will make the construction of the needle clear. For ease in handling,
each needle is mounted in a flat-sided holder, at the rear of which
is a circular orifice which enables it to slide on to a tube on the
body of the endoscope. This tube is on a swivel operated by a
lever, and when lowered into the horizontal position, transmits a
powerful beam of light from a carbon arc, passed into the tube
from condensing lenses. Light from the arc passes along the
needle until it meets the first of the two mirrors, whence it is
reflected through the small hole, in a direction at right-angles to
its original path.

When a pearl is threaded on to the needle and passed along it,
the light from the needle penetrates into the body of the pearl.
The really remarkable discovery made by Chilowsky and Perrin
was that *in a natural pearl the tiny beam of light travels mainly round the
major concentric layers of growth within the pearl*. It thus happens that,
when the two mirrors are equidistant from the centre of the pearl,
light travels from one to the other round the curved pearly layers,

and can be seen as a little flash or maximum of light by an observer who is watching the end of the needle through a low-power microscope. The diagram should make this clear.

In practice everything is conveniently arranged for the operator. The endoscope is accommodated on a table which has two 'decks'. Under the top deck is fixed a low-power lamp which enables the expert to thread the pearls to be tested on the appropriate needle. Three sizes are commonly in use—3/10, 4/10, and 5/10 mm in diameter: they are easily broken and difficult and expensive to make. Drill-holes, even of new pearls, are seldom less than 3/10 mm diameter, and if they are smaller they should in any case be opened slightly with a pearl broacher to enable the stringer to
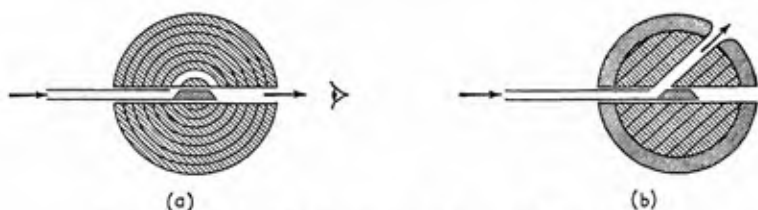
Figure 86. Principle of endoscope: (a) path of light in natural pearl (b) path of light in cultured pearl

use silk of sufficient strength for safety in wear. Pearls and needles are best kept on a tray lined with black baize on the lower deck.

The needle, with the pearl on it, is placed in position on the endoscope, sliding on to the tube already mentioned above. The pearl is gripped lightly in a small vice connected to a lever which enables the operator to pass it to and fro along the needle while watching through the microscope for any sign of a 'flash'. The 'flash', when properly focused, can be seen to consist of illuminated layers of the pearl. Even if no perceptible flash is seen, structure lines near the centre of the pearl are a sure sign that it is concentric throughout and therefore natural in origin. The exterior of the pearl can also be viewed in a mirror which is fixed above it at the correct angle, a lens also being incorporated, giving the operator a magnified image. With natural pearls the whole bead is seen to be more or less evenly suffused with light, except in the case of dark-centred pearls ('blue pearls') in which the light may be

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completely blotted out when the needle is in the central position. Such pearls, of course, will show no flash either. But a glance down the drill hole with a lens in such cases will show the operator the cause of these effects, and also assure him that the pearl is natural.

With cultured pearls no structure lines and no increase in illumination can be seen near the centre of the pearl. As the pearl is caused to slide along the needle, the sharp line of demarcation can be seen where the nucleus begins, and at this point there is a slight increase in illumination. Beyond that, there is a structure-less grey region (the bead) seen in the mirror at the needle's end. But the best positive test for a cultured pearl is provided by its

Figure 87. Endoscope needle in genuine pearl, showing 'flash' as seen by observer through microscope eyepiece

exterior appearance on the endoscope. The light from the needle traverses the flat layers of the mother-of-pearl bead which forms the nucleus and appears as a streak of light like a 'cat's-eye' at the surface of the pearl. This ray girdles the pearl and can be seen to move when the pearl is rotated on the needle with the tip of the finger, the vice being slightly loosened.

Much practice is needed before the endoscope can be used with speed and certainty; but the skilled user can test up to 200 pearls an hour with its aid. The apparatus is of course intended for use with drilled pearls only, though often partly drilled cultured pearls can be detected by means of the external ' streak' when placed on the endoscope needle.

For the majority of part-drilled and undrilled pearls, X-rays provide the most powerful testing methods. X-rays were in fact

applied soon after the first advent of cultured pearls in the early twenties in an attempt to distinguish between these and natural pearls. The techniques were, however, not refined enough, and the method was for many years undeservedly discredited, at least so far as direct radiography was concerned. It is largely to the credit of the American ceramist and gemmologist Dr A. E. Alexander that the method was rehabilitated and the techniques improved sufficiently to make it one of the most generally favoured processes for pearl-testing in the different centres where such work is carried out.

In essence the method is simple enough, but it needs considerable technical skill to obtain good photographs and great care and experience in interpreting results if mistakes are to be avoided. The 'radiability' (transparency to X-rays) of the mother-of-pearl bead used for the nucleus of cultured pearls is very little greater than that of the surrounding nacre. But the oyster almost invariably deposits a thin layer of conchyolin round the bead before proceeding to add the desired coatings of nacreous substance. Thus a good radiograph of a cultured pearl necklace will show in almost every instance a clear-cut black line round the spherical margin of the bead. When one speaks of a 'black line' the negative picture is of course referred to.

In natural pearls, however, the layers of growth which are visible to the eye in a sectioned pearl, or with a lens when looking down the drill-hole, are not always visible on an X-ray photograph, however excellently taken, and one is thus sometimes left with only the strong supposition that the pearl is genuine. There are also dangerous cases where the presence of a circular ring in the radiograph of a natural pearl may give the strong suggestion of an included bead. Careful inspection of such apparently perfect rings will usually show a slightly 'broken' margin at one point, and perhaps traces of further structures inside the circle, showing that it cannot be a bead. Further, looked at against a light with the naked eye it can be seen that the pseudo bead at the centre of the pearl is slightly more transparent to the rays than its surroundings, whereas the core of a cultured pearl when similarly observed is seen to be slightly more opaque than its outer nacreous coating.

In the Laboratory of the London Chamber of Commerce it is our practice to use radiography chiefly (a) as a means for condemning complete cultured pearl necklaces, the nature of which

has already been virtually determined by visual inspection—this saves the trouble and time of cutting them from their string for an endoscope test, and the expense of restringing—and (b) as a preliminary assay for part-drilled or undrilled pearls. Cultured pearls will usually reveal themselves unequivocally, as already explained, and many genuine pearls also, particularly if they be drop-shaped or button-shaped, as is often the case with such pearls. The operator examines the fine-grained negatives with a $10 \times$ lens in front of a good bench lamp, and learns to interpret the fine structure lines which can safely be taken as proof of natural origin. The position and shape of these is often not what one would expect
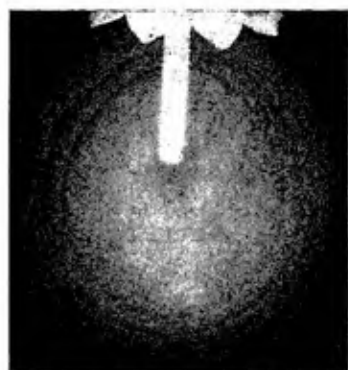
Figure 88. *Radiograph of natural pearl*
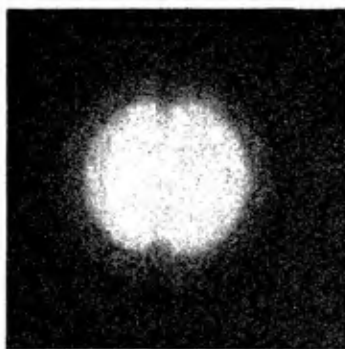
Figure 89. *Radiograph of cultured pearl*

a priori. In drop pearls, for instance, one often sees an arc-shaped line crossing not far from the narrower end, which is curved in a similar sense to the domed outline of the top of the pearl. A small round patch of relative transparency in the centre of the pearl is a sure and welcome sign that the pearl is genuine.

Those pearls which are not satisfactorily proven by radiography are then subjected to the more stringent test of X-ray diffraction, often loosely though conveniently called the 'Laue' method, though the form of X-ray analysis first initiated by Max von Laue in 1912 dealt exclusively with single crystals—not, as here, with a roughly ordered aggregate of microscopic crystallites.

When a narrow beam of X-rays is passed through a crystal on to a photographic plate or film a number of faint spots can be

seen on the developed negative surrounding the heavy trace due to the undeviated beam. If the direction of the beam coincides with a symmetry axis of a single crystal, the spots are found to form a regular pattern in correspondence with the symmetry of the crystal in this direction. Each spot can in fact be considered as due to the diffraction or reflection of part of the rays by one particular series of parallel planes of atoms within the crystal. Reflection can only take place at certain angles where 'Bragg's Law', $n\lambda = 2d \sin \theta$, is satisfied, where n is a small whole number, d the spacing between the atomic planes concerned, θ the angle of incidence, and λ the wave-length of the X-rays used. Now if one spot is produced by a given series of parallel atomic planes, and the rays are parallel to a symmetry axis, it follows that other precisely similar spots must be produced in accordance with the symmetry of the crystal. In a hexagonal crystal such as beryl, for instance, a beam of rays passing down the sixfold axis forms a 'laue photograph' displaying a beautiful sixfold symmetry pattern. A beam passed at right-angles to this would give a picture showing only twofold symmetry.

Now a natural pearl, in addition to its well-known concentric structure, also has a radial structure, since the tiny crystallites of aragonite of which it is chiefly built are disposed at right-angles to the growth layers. Thus a beam of X-rays passing through the centre of the pearl is passing down the pseudo-hexagonal axes of thousands of tiny crystals, and a diffraction photograph of the transmitted beam shows in general a roughly hexagonal series of spots round the main central trace. In some cases the spots are linked together to make a closed hexagon, while in others a broad ring or 'halo' is seen, It is an interesting fact that in button pearls, and to some extent in drop pearls, a halo pattern is seen when the beam has passed down the symmetry axis of the pearl, whereas in pictures taken with the beam at right-angles to this a well-defined spot pattern is the rule.

In cultured pearls the effect due to the outer skin is negligible unless the skin is unusually thick, and the pattern of spots produced will depend upon the orientation of the mother-of-pearl nucleus with respect to the X-ray beam. If the beam is passing at right-angles to the layered structure of the bead, this means that it is passing down the pseudo-hexagonal symmetry axis of the crystallites, which are oriented at right-angles to the layers. Thus in this

direction, or at small angles to it, a hexagonal pattern of spots is obtained as in a natural pearl. In directions parallel to the layers, or near to this, the beam is traversing the crystallites in a direction of two-fold symmetry, and this is reflected in the spot pattern, which shows a maltese cross or rectangular design, with four spots round the main trace as the most important and persistent feature. The photographs reproduced as Figure 90(a) and (b) will make clear the nature of the genuine pearl and cultured pearl patterns, and the marked differences between them. In testing pearls by the diffraction method, if the four spots of the cultured pearl pattern are clearly shown on the first trial position, there is no need to go any further: the pearl is cultured. If a hexagonal pattern or indeterminate picture is the first result, the pearl must then be
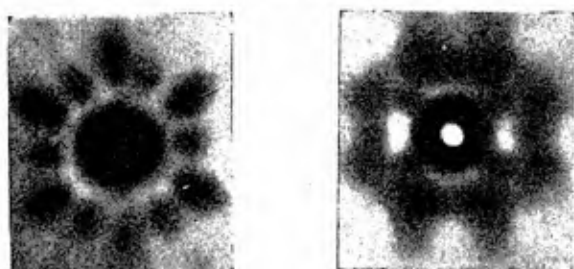
(a)   (b)
Figure 90. X-ray diffraction photographs:
(a) natural pearl (b) cultured pearl

turned through 90° and a second picture taken. A second hexagon means the pearl is genuine, since a cultured pearl must show the incriminating four spots if turned 90° from a direction in which it does not.

There are of course difficult cases, where the outer skin of a cultured pearl is abnormally thick, or the nucleus either of a natural or a cultured pearl is displaced from its normal position near the 'centre of gravity' of the pearl. Direct radiography can be used with profit to act as a check in such cases. A great deal depends upon the excellence of the pictures and the experience of the operator in interpreting his results. It is worth remembering, for instance, that in a spherical or near spherical pearl the patterns found when diffraction photographs are taken in two different directions should be practically the same: any irregularities in the pattern will be seen in each picture, and this confirms that

the pearl is indeed genuine. One also gets to recognize the curious 'kite'-shaped pattern associated with a cultured pearl when the beam is passing in an intermediate position.

Many people have condemned this method as unsatisfactory because the diffraction photographs they have seen have been thoroughly bad—usually because the size of diaphragm used is too large and the pearl-to-film distance too small for the outer spot pattern to be clear of the heavy central trace. If the film is too far away, on the other hand, or the diaphragm too small, exposure times will be inconveniently long. In the London Laboratory we find that a pearl-to-film distance of 7 cm and a diaphragm consisting of a lead block pierced with a hole 0·7 mm in diameter gives very good pictures. Fast double-coated X-ray film is used in a metal Kodak cassette with intensifying screen at front and rear. With a Machlett X-ray tube with molybdenum anticathode and two beryllium windows from which the rays emerge, and the set running at 50 KV and 20 mA, exposures of from three to six minutes (according to the size of pearl) are all that is needed, and two pearls can be photographed at the same time. It will be noticed that small pearls give larger patterns than big pearls, since in the latter the longer waves emitted by the tube (i.e. the 'softer' radiation) are absorbed by the pearl and the shorter wavelengths produce a smaller pattern.

Reverting for a moment to the conditions for taking good pictures of pearls by direct radiography. One essential, if the delicate structures sought for are to be reproduced, is to use really fine-grained film, on which a $10 \times$ loupe can be used with profit. For cultured pearls, particularly if these have thin skins, it is important not to over-expose or over-develop the image, as the fine line indicating the junction of the bead with the outer skin may otherwise be lost. On the other hand with genuine pearls a certain degree of over-exposure may be advantageous to bring out the fainter internal structures. Makers such as Ilford and Kodak produce dental films wrapped in pairs, and these are advantageously used in pearl testing, since one film of the pair can be developed more than the other, thus simulating an exposure range. Intensifying screens should on no account be used in such tests. Dr Alexander and others following him have claimed that better radiographs of pearl are obtained when the pearls are immersed to a depth of about half their diameter in a liquid such as carbon tetrachloride,

which has a 'radiability' somewhat similar to that of pearl. This is supposed to limit the fogging due to scattering of soft X-rays and lessen the troubles due to the sphericity of the pearls. There is probably some truth in this, but, after following this inconvenient and messy process (involving a liquid-tight plastic dish in which the pearls can be immersed) for some time, it was found that quite comparable results could be obtained by lightly imbedding the pearls in a thin layer of plasticine, or even by placing them on the wrapped film quite 'naked and unashamed'.

It should perhaps be mentioned, before leaving the subject of radiography in pearl testing, that imitation pearls are immediately revealed by such X-ray pictures. Either they show as opaque disks—this being the case with solid glass pearls—or else they show a thin opaque or nearly opaque circle with a nearly transparent centre—this representing the type which is made from hollow glass beads filled with wax.

So far only methods based on visual inspection or those involving expensive instruments and careful training have been suggested to the reader. But there is one test which is fairly simple to carry out and which is quite independent of any judgement based on visual appearances which can be suggested here. This depends upon the perceptible difference between the *average* density of cultured and oriental pearls, and involves the use of the heavy liquid bromoform, already mentioned in Chapter 5. If the test is to be confined to a single liquid it is best to dilute the bromoform with monobromonaphthalene, benzene, or toluene, until a piece of Iceland spar (pure calcite) used as an indicator, just slowly rises to the surface. Pure calcite has a density of 2·710, so that we can reckon such a liquid to have a density of 2·715 or 2·720. In such a liquid the majority of oriental pearls will float (on the average, about 80 per cent), and any which sink will only do so slowly, whereas the majority of cultured pearls will sink (on the average over 90 per cent), some of them quite decisively. The density figure 2·74 can be considered the upper limit for Persian Gulf pearls, whereas with cultured pearls of ordinary quality more than 60 per cent exceed this figure. Venezuelan and freshwater pearls have a less sharply defined range, but are on the average also less dense than cultured types. Australian pearls alone amongst natural pearls approach cultured pearls in density, and even with these the average is definitely not so high, less than 25

per cent exceeding 2·74. Those interested will find fuller details given in a paper by Anderson and Payne (*Gemmologist*, May 1939).

To continue with practical directions for the test: the pearls should be stirred briskly in the liquid, contained in a suitable small beaker, to shake out any air bubbles from the drill-holes which might make pearls float which otherwise might sink. It is convenient to decant the liquid and floating pearls into a glass funnel lined with a folded filter-paper, allowing the liquid to filter away into a second beaker. The pearls can then be rinsed in clean

Figure 91.   Surface of imitation pearl showing underlying glass bead near drill-hole

benzene and counted. The remaining pearls, left at the bottom of the first vessel, can then also be cleaned and counted. In testing part-drilled pearls the air-bubbles in the holes are more difficult to dislodge and it may be necessary to insert a pearl broacher or pin into the holes while they are under the liquid to release the imprisoned air.

So long as fresh bromoform is used to make the original 2·72 mixture there will be no danger of harming pearls by immersing

them in the liquid, particularly if they are then rinsed immediately afterwards with benzene as suggested and dried on a soft cloth or washleather. It is necessary to warn the reader, however, that if bromoform is kept for any length of time unmixed with any other liquid it tends to decompose, with liberation of bromine and some acid which will have a harmful effect on the surface of pearls. A warning sign that this decomposition has taken place is the presence of dark red flecks of bromine on the surface of the liquid. The bromoform can be rendered harmless again by stirring with carbonate of soda (which neutralizes the acid) and filtering.

In addition to the pearls produced by different varieties of the so-called pearl 'oyster' and the freshwater pearl mussels, pearls are also yielded by the shell-fish known as abalones, by the Pinna, the giant clam and the great conch. Pearls from these last two molluscs cannot be classed as true pearls, as they are not nacreous —that is, they have not the fine overlapping plates of nacre which cause the true pearly lustre. Products of the conch, *strombus gigas*, commonly called **pink pearls**, have a distinct beauty of their own, and fine specimens are quite valuable. At first sight they look like polished pink porcelain, or polished coral, but they show a silvery sheen at certain angles by reflected light, and under a lens or microscope reveal an attractive flame-like surface figuring by which they can be recognized. Pink pearls can also be distinguished from coral by their high density (2·83–2·86), the density of coral being about 2·69. Pearls of a kind, and very similar in nature to the conch pearls just described, come from the giant clam *tridacna gigas*. These have a density and structure not unlike conch pearls, but are mainly white. Their patterning is not so attractive as in pink pearl, and they are seldom seen in jewellery.

Shiny, non-nacreous black or dark brown pearls like boot-buttons are sometimes seen, which are called clam pearls in the trade, though their precise origin is obscure.

Imitation pearls, however cleverly made, are not difficult to detect on close inspection. Their pearly lustre is due to a mixture containing fish-scales (*essence d'orient*) which is applied either to the interior of a glass bead or to the exterior of a bead of glass, mother-of-pearl, or other substance. The best quality imitations are based on beads cleverly shaped to resemble pearls, and receive a number of coatings of the pearly essence. In no case does the surface show the finely spaced parallel serrated markings which

are typical of natural and cultured pearls and are a sure sign of growth within the oyster.

Imitation pearls feel smooth between the teeth, oyster pearls feel gritty by comparison. Perhaps the best and simplest test is to examine the edges of the drill-holes with a lens, since here the glassy nature of the bead will be revealed, or, if it be some other material, there will be at least some signs of peeling of the applied coating. In Figure 91 the surface of an imitation pearl is somewhat unkindly revealed under a magnification of some 15 diameters. It will be seen that the coating has become worn away near the drill-hole, revealing the milky glass bead beneath.

Figure 92.   Surface structure of pink (conch) pearl

Determinations by Robert Webster on a large number of imitation pearls of the two main types have shown that the density of solid imitation pearls is appreciably higher than for oyster pearls; the normal range being 2·85 to 3·18. In more recent tests some pearl beads of inferior quality were found to have the very low density of 2·33, and others of better appearance have been measured, having a density of 2·53. The latter featured as evidence in a notorious murder case.

The wax-filled type have a far lower density than the solid beads—for the most part below 1·55. Coated plastic beads and coated mother-of-pearl beads have both been used on occasions as imitation pearls.

Polished beads of **haematite** are occasionally seen masquerading as black pearls, but can usually be detected at sight by the

lack of pearly lustre. Haematite gives a red 'streak' when rubbed on an unglazed·porcelain plate, and, if it can be obtained free from its setting, its high density of approximately 5·1 is a very distinctive feature.

STAINED PEARLS

Pearls can be stained or tinted by treatment with various dye-stuffs. With genuine pearls this is seldom done, except in the case of black pearls. With these, it is not infrequent to find that the
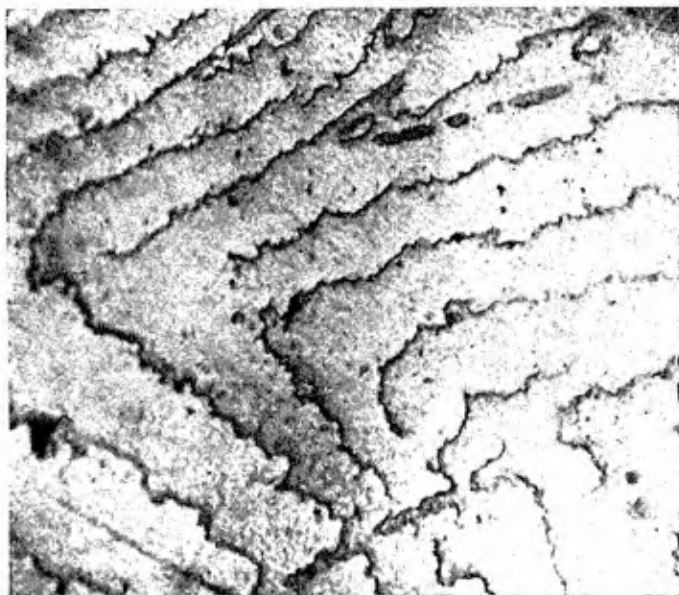
(*Photo: V. G. Hinton*)

Figure 93. Surface structure of mother-of-pearl magnified approximately 100 times. Pearl shows a similar structure

colour has been 'improved'—or at least intensified—by treatment with silver nitrate. Any pearl which shows a very homogeneous and intense black colour can be viewed with suspicion: the natural 'black' pearls are seldom really black. Bronze or gun-metal, shades of grey, and a blue-black with subtle iridescence, as on the plumage of a magpie in good condition, are the approved natural colours.

If the pearl is partly drilled, the silver nitrate will have seeped

between the pearly layers to some extent, and an X-ray photograph will then reveal its presence by thin white lines on the negative, as first pointed out by Mr Robert Webster. Another test for staining by silver nitrate is the masking effect this has on the fluorescence of the treated pearls under long-wave ultra-violet light or between crossed filters. Bathed in a strong beam of light filtered through copper sulphate solution, natural black pearls show a dim red glow through a red filter. Stained black pearls remain inert.

If black pearls are found to be cultured, this means *ipso facto* that the pearls are stained: but in such a case this hardly matters. It may be useful to warn those who employ radiography in testing pearls that the presence of silver nitrate in the layer of discontinuity between the bead and the outer skin may largely neutralize the radiability of the conchyolin layer, which normally shows a dark line on the negative, and make the radiograph less easy to interpret.

Lastly, one may mention that another manner in which X-rays can assist in distinguishing cultured from natural pearls is by the fluorescence they excite in the various sorts of pearl. The bead forming the core of a cultured pearl is almost invariably made from freshwater mother-of-pearl. This contains a trace of manganese, which causes it to emit a distinct greenish fluorescence under X-rays. This fluorescence can be quite easily seen in the majority of cultured pearls, shining through the translucent outer skins, provided some arrangement is made whereby the effect can be studied in darkness through a heavy lead-glass window, with the whole apparatus properly screened to avoid exposing the operator to any of the highly dangerous X-radiation.

The careful observer will detect a short phosphorescent afterglow with cultured pearls when the rays are cut off. The only type of natural pearls to show fluorescence comparable in strength with that shown by cultured pearls are those from freshwater mussels, but the colour of the fluorescent glow is rather different here, being yellowish in tint. Australian pearls show a fainter fluorescence, and Persian Gulf pearls even less. The method is attractive in its speed and simplicity, but can easily lead to mistakes if relied upon too heavily: it is best to regard it as a useful accessory test.

FLUORESCENCE AS AN AID TO IDENTIFICATION

SEVERAL references to the fluorescence shown by certain gems have been made in the foregoing pages, but no clear explanation of the phenomenon or instructions as to how best it may be observed have been given.

This will now be remedied, and a more coherent and orderly description be given of specific cases. In accordance with the principles of this book, however, only those luminescent effects which the author himself has observed and found useful or interesting will be included.

First, what exactly is fluorescence? It is the emission of visible light by a substance under the stimulus of visible or invisible radiations of shorter wavelength. If the fluorescent glow persists for an appreciable time after the stimulating rays have been cut off, this afterglow is termed 'phosphorescence'. Sometimes the phosphorescence may differ in colour from the original fluorescence. This happens when some of the wavelengths composing the fluorescent glow are extinguished so soon as the stimulus is removed, while others decay more slowly, and persist. 'Luminescence' is a convenient term to cover both fluorescence and phosphorescence. 'Thermophosphorescence' is seen when certain stones, at some time after irradiation, are seen to emit visible light on warming. The phosphorescence in such cases is considered to be 'frozen in', and needs heat energy to release it.

In the Precious Stone Laboratory of the London Chamber of Commerce four types of radiation are in common use for producing fluorescence, and their effects are often distinctly different on any one specimen. Each has its own special value in certain cases.

The first to consider, on account of its simplicity, is merely visible light of the blue and violet regions, produced by passing a powerful beam of light from a 500-W projection lamp through a flask containing a strong solution of copper sulphate. The flask should conveniently be one of 600- or 750-ml capacity, and this serves as a filter and condensing lens combined. It is well worthwhile making the solution with distilled water to avoid any trace of milkiness—and even so, filtering may be necessary to obtain a

crystal-clear liquid. The copper sulphate absorbs all red, orange, and yellow light, so that the filtered rays are invisible when viewed through a good red or orange filter. If any substance, therefore, which is placed in a beam of the blue light and is not otherwise illuminated is seen to glow when viewed through one of these filters, it must be exhibiting fluorescence—i.e. be absorbing energy from the blue-violet light and re-emitting part of the energy as light of longer wavelength.

This technique of using 'crossed filters' to observe fluorescence was first devised by the great British physicist George Gabriel Stokes in 1852, when he established the true nature of fluorescence for the first time. The author adapted the method as a lecture demonstration, but found it so sensitive and useful for testing gems which have a red or orange fluorescence that it has been constantly used in the London Laboratory ever since.

The second and by far the most popular method for stimulating fluorescence is by means of a high-pressure mercury discharge lamp housed in a fused quartz tube, the light from which is filtered through 'Wood's glass'. Wood's glass is a dark glass containing cobalt and some 4 per cent nickel, and is named after a great American pioneer in physical optics, R. W. Wood, who first proposed its use. This filter cuts out most of the four strong mercury lines in the visible spectrum, and transmits those in the near ultraviolet, notably a powerful line at 3650 Å, which does most of the work in stimulating fluorescence. Hanovia Ltd and a few other manufacturers supply several forms of such 'analytical' lamps, which have considerable use in industry for detecting impurities etc. in manufactured products. Medical 'sun lamps' are of this type, but lack the Wood's glass filter. Without the filter any fluorescent effects would of course be lost in the intense glare of the unshielded lamp.

Rather less effective lamps can be home-made by using an arc lamp with special charged carbons emitting a rich ultra-violet spectrum—or even a photoflood lamp—and filtering the light through a piece of Wood's glass mounted in an opaque screen.

The third form of radiation is 'short-wave' ultra-violet light emitted by a low-pressure quartz-mercury lamp in which the 2537 Å mercury line is preponderant. Wood's glass does not transmit this line, and a special filter such as Chance's OX 7 glass has to be used. Unfortunately a good deal of visible light also passes

through this filter. Convenient short-wave lamps are more easily obtained in the U.S.A. than in Britain; but a small 'germicidal' lamp made by Philips, used with an OX 7 filter, has proved very effective, despite its low power. Robert Webster was the first to draw attention to this inexpensive little lamp. Effects are in most cases less spectacular than under long-wave ultra-violet, but in some important instances are more diagnostic.

X-rays, the fourth source of radiation, are not usually available to the amateur gemmologist, and, moreover, they are dangerous in use unless very carefully shielded. Fluorescent effects under these rays must be viewed through a thick lead-glass window. Several gemstones are known to alter in colour when exposed to X-rays, and even ultra-violet light may cause discoloration in white and blue zircons, so that prolonged exposure must be carefully avoided.

Broadly speaking, for gems showing a red fluorescence the 'crossed filter' technique is the most convenient, and the most sensitive. For stones showing green or blue fluorescence, long-wave ultra-violet rays are generally the best to use, while only in special cases need short ultra-violet or X-rays be resorted to because of some specific reaction not found under the other radiations.

CROSSED FILTERS

A red fluorescence is one of the peculiarities of minerals owing their colour to a trace of chromium. Thus it is that ruby, red spinel, alexandrite, emerald, and pink topaz all show up well between crossed filters. Synthetic sapphires of the 'alexandrite' type, most synthetic blue spinels and synthetic green sapphires also glow red under the same conditions. Of these, Burma and synthetic rubies and clear red or pink spinels glow the most brightly: the new synthetic red spinels are also quite strongly fluorescent. The spectroscope is valuable here in making the test more specific, and enables one to distinguish between ruby and spinel. Ruby and synthetic ruby have an identical fluorescence spectrum, in which the doublet at 6928 and 6942 Å appears as a single intense line. Only faint indications can be seen of fluorescence lines on either side of this. Natural spinel, on the other hand, displays a group of several narrow lines, like a set of organ pipes, of which two of almost equal strength are in the middle.

Most curiously, synthetic spinel, whether it is made by the Verneuil process or by the mysterious crystallization referred to on page 86, has not got quite the same spectrum, but shows a single predominant line near 6850 Å against a background of fainter lines. Thus in appearance these synthetic spinels show a spectrum rather closely resembling that of ruby. There should be enough of the 'organ pipe' effect to enable a distinction to be made, but a glance in the blue part of the spectrum (transmitted by the copper sulphate flask filter) will settle the issue, as ruby will show its three strong narrow absorption lines in this region, whereas there are no lines in the blue in red spinel.

Alexandrites and emeralds vary in their response according to their chromium content and the degree to which iron is present. In each case the red fluorescence will serve to distinguish between the chrome-bearing varieties emerald and alexandrite and ordinary beryl and chrysoberyl respectively. Synthetic emerald shows a stronger glow than most natural emeralds, while those from S. Africa or India, which contain iron, display practically no fluorescence.

Pink topaz shows quite a distinct glow, emanating chiefly from an unresolved doublet at 6820 Å. One must guard against confusing pink topaz with pink sapphire on this account. Pink sapphire has a far brighter fluorescence line, but it is better to check any suppositions by means of the refractometer or some other definite test. Some kyanites, whether blue or green, contain enough chromium to show a dim red fluorescence.

So much for chromium fluorescence under crossed filters. Such fluorescence is truly red, but the red seen through the viewing filter in certain other cases may be only part of an extensive fluorescence system which, if seen *in toto* under ultra-violet light, would give a different colour effect. For instance, between crossed filters strontium titanate shows a faint red glow—but so do many diamonds which in ultra-violet light are strongly blue-, green-, or yellow-fluorescent.

A test between crossed filters is of practical value in the case of black pearls. If these are of natural colour they show a dim red glow through the viewing filter: if stained with silver nitrate this effect is not apparent.

By using saturated copper sulphate solution and a carefully chosen yellow filter one can still maintain the 'crossed' effect, and

this enables orange and yellow fluorescent subjects to show good results—Ceylon yellow sapphire, for instance. Ammoniacal copper sulphate, which has a far darker colour, enables one to cover the green also. But the strength of the transmitted light is much diminished, and the particular advantages of the crossed filter technique compared with ultra-violet light is largely lost.

LONG-WAVE ULTRA-VIOLET LIGHT

In theory, all those materials which show a red fluorescence due to chromium between crossed filters should also show the effect under the conventional 3650 Å light from a mercury lamp filtered through Wood's glass. With ruby and red spinel, indeed, the red glow is quite spectacular, but the dimmer effects with such stones as emerald and alexandrite are undeniably more easily observed by the crossed filter technique.

Fluorescence displays in museums or gem exhibitions will usually be found to contain some half-dozen mineral varieties which can be guaranteed to yield a fine show of colours under ultra-violet light. Though these are hardly gem materials it may be useful to list some of them here, as anyone investing in an ultra violet lamp will enjoy assembling an attractive group of specimens to show it off.

Fluorspar is an essential constituent in any such display. The very name 'fluorescence' is derived from the magnificent violet glow that most specimens of this attractive mineral emit under these invisible rays. The fluorescence is also excited by ordinary daylight; and often for this reason green crystals of fluorite have a purple appearance unless light is transmitted directly through them, in much the same way that reddish-brown lubricating oils appear green by reflected light because of their fluorescence. Curiously enough, the massive banded fluor mined in Derbyshire which is known as 'blue-John' and has been used for centuries for vases, boxes, and ornamental objects, is not at all fluorescent under ultra-violet rays. An interesting fact about some purple fluorspar is that after stimulation with ultra-violet light it continues for a long time to emit an invisible fluorescence of ultra-violet rays—a fact easily demonstrated by placing an irradiated specimen on a photographic film in a light-tight box for some hours. After development an 'auto-image' will be clearly seen where the crystal made contact with the film. Recent experiments by the author on

some necklaces of green gem fluorite failed to give this result, though the violet fluorescence was quite intense.

After fluorspar, the crystals most worthy of a place in the display are perhaps the beautiful pseudo-hexagonal crystals of aragonite which are found together with native sulphur at Girgenti in Sicily. These crystals have a lovely rose-pink fluorescence, partially masking a green component, which, when the crystals are removed from the rays, persists as a green phosphorescence for a few seconds —an astonishing phenomenon when first beheld.

Massive scapolite from Ontario provides another fine patch of colour under an ultra-violet lamp—in this case a bright orange-yellow. When examined with a spectroscope this light is seen to have a banded spectrum, typical of the fluorescent light emitted by uranium compounds. Yet another bright fluorescent colour is given by willemite from Franklin Furnace, where a trace of manganese in this zinc silicate mineral causes it to glow a brilliant green. Calcite from several favoured localities provides a beautiful rose-red glow, and pieces of 'canary glass' containing uranium yield a bright yellow-green under the rays.

Turning now to gem materials, synthetic yellow-green spinels which contain traces of manganese have a bright green fluorescence. Kunzite, and yellow topaz from Brazil show a rather weak orange glow, while white zircon and yellow apatite show a yellow fluorescence. The light emitted by zircon under the rays shows some exciting bright lines through the spectroscope, but it is unwise to expose the stone for long, as the action of the rays tends to cause it to revert to the brownish tint of the mineral as originally found. Heating to dull red heat will usually restore any spoiled stones.

Yellow and off-white sapphires from Ceylon yield a characteristic apricot-yellow fluorescence. This is of practical value in distinguishing them from synthetic yellow corundums which, in general, show no curved growth lines and, if free from bubbles, are difficult to prove.

Silicon carbide (carborundum), particularly after roasting, has an orange-yellow fluorescence, which is a useful means for detecting its presence as an impurity in diamond powders.

The fluorescence of diamond itself is mentioned last, though it is undoubtedly the most interesting and important of all. Luminescence in diamond has been known and studied for a century or

more, and still provides a major puzzle for the physicist. The majority of gem diamonds show a sky-blue to violet fluorescence under long-wave ultra-violet light, but the strength of this fluorescence varies enormously (and quite unpredictably) in intensity: some stones, in fact, are virtually inert under the rays. Attempts to ascribe this fluorescence to impurities in diamond or to correlate fluorescence with particular localities have been consistently unsuccessful. Sir C. V. Raman and his school seem on surer ground in ascribing the emission of light in diamond to electronic transitions in the carbon atom itself, modified by its lattice structure. The blue fluorescence is connected with certain definite wavelengths where discrete emission bands can be seen. The key position of the series is at 4155 Å, which is also the wavelength of the most important absorption band in diamond. There are also broad regions of continuous emission extending as far as the red end of the spectrum.

When a strongly blue-fluorescent diamond is removed from the rays and observed within the cupped hands, a fairly persistent *yellow* phosphorescence can be observed in all cases—a valuable factor in the recognition of diamonds in jewellery, since no other blue-fluorescent mineral shows this effect.

Broadly speaking, blue-fluorescent diamonds belong to the 'Cape' series. Diamonds belonging to the 'brown diamond' category tend to show a green fluorescence, which is linked to an emission and absorption band at 5040 Å—just where the green merges into the blue part of the spectrum—in the same sort of way that blue-fluorescing stones are linked to the 4155 Å band. In many stones the two systems are existent together. A third important fluorescent colour in diamond is a warm yellow—seen more often in industrial stones than in gem diamonds.

Robert Webster has proposed to make use of the highly variable fluorescent phenomena in diamond as a means of identifying important pieces of diamond-set jewellery. Each piece under ultra-violet light will show a pattern of bright, medium, and dimly-fluorescent diamonds which will be unique for that particular ornament, so that photographs of the piece in ordinary and in ultra-violet light will provide a foolproof identity document should it be lost or stolen and subsequently recovered.

SHORT-WAVE ULTRA-VIOLET LIGHT

Effects seen under short-wave mercury light, suitably filtered, with the 2537 Å line as the main activating radiation, are in a few cases more diagnostic than those given by long-wave ultra-violet light. The mineral scheelite, for instance, a calcium tungstate only occasionally cut as a collector's item, is inert under 3650 Å rays, but glows a bright whitish blue under the 2537 Å radiation.

Of more practical value to the gemmologist is the reaction of most white synthetic spinels, which (as discovered by Robert Webster) fluoresce with a strong bluish-white glow under the short waves. Under these conditions synthetic white sapphires show a very weak deep blue. A short-wave lamp is thus of some assistance in testing jewellery set with small colourless baguettes purporting to be diamond, which may be difficult to identify by conventional methods. Webster also found that the rare blue gemstone benitoite shows a bright blue fluorescence under short-wave ultra-violet light.

Quite apart from fluorescence effects, the value of a short-wave lamp in differentiating between synthetic and natural rubies and emeralds has already been mentioned earlier in the book. In each case the synthetic stones are much more transparent to short-wave light than the natural specimens, and the degree of transparency of any sample can be quickly determined by the method suggested by Mr Norman Day. The stone or stones are placed (in a darkened room) on a piece of contact printing paper immersed in a dish of water, and exposed for a few seconds to the rays from a short-wave lamp placed some 15 in. above the dish. The developed paper will show quite clearly the relative transparency of the stones to the rays. Since the exposure time is rather critical for this experiment, it is wise always to include known synthetic and natural stones to act as standards for comparison.

X-RAYS

In general, fluorescence under X-rays is very similar to the effects seen under ultra-violet light. Rubies and synthetic rubies, for instance, show a red glow due to their chromium content. When the rays are switched off, however, synthetic rubies show a distinct after-glow when observed with dark-adapted eyes, and

this phosphorescence may persist for ten seconds or in some cases for very much longer. With natural rubies, on the other hand, the glow is extinguished instantaneously. Synthetic rubies can be relied upon to show curved structure-lines when viewed at the correct angle, but when mounted in, say, an eternity ring, the viewing angle is very limited and no structure lines seen. In such cases the test for phosphorescence under X-rays provides a much-needed confirmatory method.

We have remarked how variable in intensity and, to some extent, in colour is the fluorescence of diamond. Under X-rays the effects seen are far more uniform: almost all stones glowing with a chalky blue tint of moderate intensity. There is seldom any appreciable phosphorescence. Some diamonds which show a green fluorescence under ultra-violet light give a similar glow of colour under X-rays.

An interesting and unexpected orange fluorescence is seen when massive green grossular garnet (the so-called 'Transvaal jade') is placed under X-rays. This effect is distinctive enough to form a useful test for this rather attractive jade substitute.

It has long been known that cultured pearls tend to show a yellowish fluorescence under X-rays, while most natural salt-water pearls show a glow so dim that it can only be seen with dark-adapted eyes. The glow in cultured pearls is due to the presence of traces of manganese in the nucleus which is usually fashioned from mother-of-pearl derived from freshwater mussels. It is hardly surprising that natural freshwater pearls should also show a yellowish fluorescence for the same reason. Careful observation will show that the fluorescence is chiefly at the surface of the pearl, while in cultured pearls the glow comes from within. Though useful as a confirmatory test or as a warning sign, X-ray fluorescence should never be considered as a substitute for the more stringent methods of testing pearls outlined in the previous chapter.

Only the more outstanding fluorescent effects have been mentioned above. Those seeking more complete data should consult the series of eleven articles written by Mr Robert Webster, which appeared in the *Gemmologist* from June 1953–April 1954.

APPENDIX

GLOSSARY

Absorption spectrum.—When white light passes through a coloured stone, light of certain wavelengths is absorbed more strongly than others, the colours least absorbed combining to produce the colour of the stone. When viewed through a spectroscope, the colours most strongly absorbed may show as dark bands crossing the spectrum in characteristic positions. Such a spectrum is known as an absorption spectrum, and provides a useful means of identification. (Chapter 8.)

Allochromatic minerals.—Minerals which would be colourless if chemically pure, but which commonly exhibit a range of colours due to the presence of small quantities of one or more 'colouring' elements. Chief amongst these elements are those having atomic numbers, 22–29; viz., titanium, vanadium, chromium, manganese, iron, cobalt, nickel, and copper. Corundum, beryl, spinel, and quartz are examples of allochromatic gemstones. (See Idiochromatic Minerals.)

Amorphous.—Literally, 'without shape'. An amorphous substance is one in which the internal arrangement of the atoms or molecules is irregular and which in consequence has no characteristic external form. (See under 'Crystal'.)

Ångström unit.—Convenient unit of length for measurement of wavelengths of visible light and most X-rays. $1 \text{ Å} = 0.0000001$ millimetre.

Anisotropic.—A term for crystals in which the optical properties vary with direction. All crystals save those in the cubic system are anisotropic and exhibit double refraction.

Asterism.—The star effect seen by reflected light in stones containing suitably oriented rod-like inclusions or channels when these are cut *en cabochon* in the correct direction.

Atom.—A unit which is the smallest part of a chemical element which remains unchanged during all chemical reactions. Although partly composed of electrically charged units such as electrons, protons, etc., atoms as a whole are electrically neutral.

Atomic weight.—The weight of an atom compared with an atom of oxygen $= 16.00$.

Biaxial.—The optical character of crystals belonging to the rhombic, monoclinic, and triclinic systems, which exhibit double refraction, but have two directions of single refraction, i.e., two optic axes.

Birefringence.—Synonymous with double refraction, which see.

Boule.—The form, shaped somewhat like an inverted pear, assumed by synthetic corundum or spinel when produced under the inverted blow-pipe of a Verneuil furnace.

Brilliant.—The most effective form of cutting for diamond, and so usual for this mineral that the term 'brilliant' is equivalent to 'brilliant-cut diamond' in trade parlance. Brilliant-cut is also used for zircons and other stones. The standard brilliant has 58 facets; 33 in the crown and 25 in the base.

Cabochon.—A style of cutting in which the top of the stone forms a curved convex surface. The base may be convex, concave, or flat.

Carat.—The metric carat, equivalent to one-fifth of a gram, is internationally accepted as the standard weight for precious stones. There are 141·75 carats in one ounce avoirdupois.

Chatoyancy.—The 'cat's-eye' effect, due to the reflection of light from fibres or channels arranged in parallel formation within a stone. A silky band of light at right-angles to the inclusions is seen when such a stone is cut *en cabochon* in the correct direction.

'Chelsea' colour filter.—An effective dichromatic colour filter transmitting light of only two wavelength regions; one in the deep red, the other in the yellow green. Useful for discriminating between emerald and its imitations and for detecting synthetic spinels and pastes coloured blue with cobalt. (Chapter 4.)

Chemical element.—Matter composed of atoms of only one chemical type and which thus cannot be decomposed into simpler substances by chemical means. There are about a hundred elements known.

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Cleavage.—The tendency shown by certain stones to split along one or more definite directions. Cleavage planes are always parallel to a possible crystal face of the mineral in question.

Critical angle.—The angle at which a ray of light in passing from a dense medium, such as a gemstone, into a rarer medium, such as air, is refracted at 90° to the normal. Any rays reaching the inter-surface at angles greater than the critical angle are unable to pass into the rarer medium, and are *totally reflected*. (Chapter 2.)

Cryptocrystalline.—The structure of a substance such as chalcedony, which consists of masses of exceedingly small crystals but shows no external sign of crystalline structure. (See Figure 73, page 225.)

Crystal.—A substance in which the constituent atoms, ions or molecules are arranged in accordance with a definite regular structure throughout. Under favourable conditions this regularity of internal structure gives rise to a symmetrical external form bounded by plane surfaces known as *crystal faces*. (Chapter 1, page 14, and Appendix, page 310.)

Crystal axes.—Imaginary lines passing through a crystal in important symmetry ·directions, intersecting in the *'origin'* at the centre of the crystal. The axes are usually three in number, and they are chosen to act as a frame of reference by means of which the relative positions of the crystal faces can be described. (See page 310.)

Crystal systems.—The six main symmetry groups into which all crystals, whether natural or artificial, can be classified. (See page 310.)

Density.—The weight of a substance per unit volume, measured in grams per cubic centimetre. Since 1 c.c. of water weighs 1 gram, the density of a substance is numerically equal to its specific gravity. (Chapter 5.)

Dichroism.—The property by which the colour of a stone varies according to the direction in which it is viewed. The two polarized rays passing along a given direction in a coloured doubly refracting mineral are often differently absorbed, and thus differ in colour when they emerge. The Two colours can be compared side by side by use of a *dichroscope*. (Chapter 4.)

Dispersion.—The difference in the refractive index of a stone for light of different wavelengths, giving rise to the flashes of spectrum colours known as 'fire'. The wavelengths usually chosen for measuring the dispersion of gemstones for comparative purposes are 6870 Å in the red and 4308 Å in the violet, corresponding to the B and G Fraunhofer lines of the solar spectrum. The B–G dispersions of some of the gemstones, multiplied by 1000, are as follows: Blende, 156; cassiterite, 71; demantoid, 57; sphene, 51; diamond, 44; zircon, 38; peridot and spinel, 20; corundum, 18; tourmaline and spodumene, 17; chrysoberyl, 15; topaz, quartz, and beryl, 14; fluorspar, 7.

Double refraction.—A ray of light entering any crystal other than cubic in directions other than that of an optic axis is at once split into two polarized rays, each vibrating at right-angles to the other. These rays travel at different speeds through the crystal, and are in consequence refracted by different amounts, the effect being known as double refraction or birefringence. The determination of double refraction in a gemstone is an important test. Where D.R. is strong, the edges of back facets as viewed through the front of a cut stone with a lens appear as double lines. (Chapter 3.)

Doublets.—Composite stones consisting wholly or (more usually) in part of genuine material. (Chapter 4.) The term doublet is also used for closely spaced lines in emission or absorption spectra.

Extinction.—When a birefringent mineral is examined between crossed Nicol prisms or Polaroid disks and no light is transmitted the mineral is said to be in a position of extinction. There are four such positions during a complete rotation of 360°.

Extraordinary ray.—That ray for which, in minerals belonging to the hexagonal and tetragonal systems, the refractive index varies according to its direction through the crystal.

Fire.—Flashes of spectrum colours from the facets of a cut stone, due to dispersion, which see.

Fluorescence.—The emission of visible light by certain minerals when exposed to radiations of shorter wavelength such as ultra-violet light or X-rays. (See Chapter 24.)

Fracture.—The nature of the broken surface of a solid substance when this does not follow a cleavage plane. The commonest type of fracture is *conchoidal* (shell-like), typical of glass, quartz, and to a lesser extent of several other gemstones. Fibrous minerals such as jade show a *splintery* fracture.

Fraunhofer lines.—Dark absorption lines which can be seen crossing the bright continuous spectrum of light from the sun, due to the absorption of light by the vapour of elements in the chromosphere. First observed by the German physicist, Fraunhofer, who designated the principal lines by letters of the alphabet. The principal lines are as follows (wavelengths in Ångström units) A, 7606; B, 6870; C, 6563; D, 5893; E, 5270; F, 4861; G, 4308; H, 3969.

Grain.—In Troy weight there are 480 grains to the ounce. Not to be confused with the **Pearl grain**, which is one quarter of a metric carat.

Habit.—The characteristic crystal form of a mineral.

Hardness.—The resistance of a mineral to abrasion. (See Mohs' scale, below.)

Idiochromatic minerals.—Minerals in which the colour is due to some essential constituent of the stone, e.g., malachite, peridot, almandine. In contrast to allochromatic minerals, those which are idiochromatic have a limited range of colour. (See Allochromatic Minerals.)

Imitation stones.—Materials such as glass or the plastics which may resemble genuine stones in colour and appearance, but differ from them in composition and physical properties.

Inclusions.—Particles of foreign matter, solid, liquid, or gaseous, enclosed within a gemstone. The nature of such inclusions provides a powerful clue to the origin of a stone, and enables natural stones to be distinguished from their synthetic counterparts.

Inorganic.—Not produced by vital processes.

Interference of light.—Rays of light pursuing the same path, in which the waves are 'out of phase', suffer interference and tend to destroy one another, while waves which are 'in phase' (crest corresponding to crest) reinforce each other. The colours seen reflected from opal and labradorite are due to interference.

Ion.—An electrically charged atom, radical or molecule.

Iridescence.—The play of rainbow colours due to interference of light as seen in the precious opal, in light reflected from cleavage cracks, on the surface of carborundum crystals, etc.

Isomorphous replacement.—Where one element in a mineral is replaced by another of similar chemical nature and ionic radius without sensibly altering the crystal structure of the mineral. Isomorphous replacement may cause wide variations in such properties as density and refractive index, as may be seen, for instance, in the garnets.

Isotropic.—The term used for those materials in which the optical character is the same in all directions. Such materials are singly refractive and show no dichroism. Cubic minerals and amorphous substances are invariably isotropic.

Light.—A form of radiant energy which gives rise to the sensation of sight. Light travels through space with a velocity of 186,285 miles per second, in common with radio and other waves of a similar physical nature but different wavelength.

Lustre.—The effect produced by light reflected from the surface of a stone. Apart from substances having a *metallic* lustre such as gold or pyrites, the lustre is chiefly determined by the refractive index and perfection of polish possessed by the stone. Since a higher degree of polish can be obtained with hard stones, hardness is also a factor of some importance. The characteristic lustre of diamond is known as *adamantine*, and is displayed in lesser degree by other stones of high R.I., such as zircon and demantoid. The majority of stones have a *vitreous* or glassy lustre. The terms *resinous, waxy, pearly,* or *silky* lustre are also used.

Mercury spectrum.—Mercury-vapour lamps of various kinds emit the following powerful lines in the visible and ultra-violet regions (wavelengths in Ångstrom units) 6907, 6234, 5790, 5769, 5460, 4358, 4046, 3650, 2536. Being rather widely-spaced,

individual lines in the visible spectrum and in the ultra-violet can be more or less isolated by the use of appropriate filters.

Metamict.—A mineral which has become virtually amorphous due to the break-down of the original crystal structure by internal bombardment with alpha-particles (helium nuclei) emitted by radio-active atoms within the mineral. Many green zircons, especially those from Ceylon, which are pre-Cambrian in age, and have thus had over 800 million years of this internal bombardment, owe their low refractive index and density to this cause, and may be termed metamict zircons.

Metric carat.—See Carat.

Mineral species.—A homogeneous substance produced by the processes of in-organic nature, having a chemical composition, crystal structure, and physical properties which are constant within narrow limits.

Mohs' scale.—A scale of hardness suggested by Friedrich Mohs over 100 years ago, and still used by mineralogists. The figures in this scale merely denote an *order* of hardness (resistance to scratching) and have no quantitative significance whatever. The minerals chosen by Mohs as standards for his scale are as follows: 1 talc, 2 gyp-sum, 3 calcite, 4 fluorspar, 5 apatite, 6 feldspar, 7 quartz, 8 topaz, 9 corundum, 10 diamond.

Molecule.—A group of two or more atoms in close combination. The smallest quantity of an element or compound which is capable of independent existence.

Monochromatic light.—Light of one wavelength only. The standard mono-chromatic light used for optical measurements is the yellow light emitted by glowing sodium vapour, which consists actually of two nearly identical wavelengths having a mean value of 5893 Å.

Nicol prism.—A special prism for producing polarized light, made from two pieces of Iceland spar (calcite) cemented together with Canada balsam. Light entering the prism is split into two polarized rays: of these, the 'ordinary' ray is totally reflected at the balsam layer while the 'extraordinary' ray is able to pass through the prism. In a petrological microscope two Nicol prisms are incorporated.

Opalescence.—A term used both for the milkiness of common opal and (more properly) for the milky iridescence seen in precious opal.

Optic axis.—A direction of single refraction in a doubly refracting mineral. Hexagonal and tetragonal minerals have one such axis, and are termed *uniaxial*; rhombic, monoclinic and triclinic minerals have two optic axes and are thus *biaxial*.

Ordinary ray.—In uniaxial stones, that ray which travels with constant velocity in any direction within the crystal.

Organic.—Produced by vital processes. In chemistry, the compounds of carbon are termed 'organic' compounds.

Orient.—The characteristic sheen and iridescence displayed by pearl.

Paste.—An imitation gemstone made from a certain type of lead glass. Loosely applied to all glass imitation gemstones.

Phosphorescence.—An effect only differing from fluorescence in that the luminous glow persists perceptibly after the removal of the exciting radiation.

Plastics.—Loose term embracing all synthetic resin-like materials which can be moulded under the influence of heat or pressure. (Chapter 22.)

Pleochroism.—A general term embracing dichroism and the similar effect shown by some biaxial stones in which three distinct colours or shades can be seen (two at a time) by means of the dichroscope.

Polarized light.—Light vibrating in one plane only. Polarized light can be produced by means of reflection from glass plates at certain angles, by absorption of one of the two polarized rays passing through dark-coloured tourmaline plates or Polaroid sheets, or by means of a Nicol prism.

Polaroid.—Sheets of plastic material containing ultra-microscopic crystals of quinine iodosulphate which have the property of transmitting only one polarized ray, the other being almost entirely absorbed by the crystals. Polaroid sheets provide a light and inexpensive substitute for Nicol prisms in the production of polarized light.

Reconstructed stones.—Stones made during last century from chips of natural ruby by fusing them together under a blowpipe flame. These so-called reconstructed rubies have been superseded for over fifty years by synthetic stones made by the

Verneuil process, for which the term should not be used. Pressed amber is the only truly 'reconstructed' gem material at present on the market.

Reflection.—A ray of light incident on a polished plane surface is reflected by it in such a manner that the angle of reflection is equal to the angle of incidence. The proportion of reflected to refracted light in transparent substances increases with the refractive index of the substance and with the angle of incidence. For example, 17 per cent of the light falling at perpendicular incidence on the surface of diamond is reflected, whereas with quartz less than 5 per cent is reflected under these conditions.

Refraction.—When a ray of light passes from air into a denser medium such as a gemstone, its velocity is lessened and as a consequence the ray no longer follows its original path but is bent or *refracted* to follow a direction more nearly perpendicular to the surface between the two media.

Refractive index.—A quantity representing the refracting power of a medium, in which air = 1·00 is in practice taken as a standard. The R.I. of a medium may be defined as the ratio of the velocity of light in air to the velocity of light in the medium, or as the ratio of the sine of the angle of incidence to the sine of the angle of refraction when light passes from air into the medium. (Chapter 2.)

Refractometer.—An instrument designed for measuring the refractive indices of various substances. (Chapter 2.)

Sheen.—The appearance caused by the reflection of light from structures inside a stone, e.g., moonstone.

Silk.—The fine intersecting rod-like crystals or cavities typically seen in Burma ruby, which give a silky sheen by reflected light.

Specific gravity.—The weight of a substance compared with the weight of an equal volume of pure water at 4 deg. Centigrade. (Chapter 5.)

Spectroscope.—An instrument which resolves light into its component wavelengths by refraction through prisms or diffraction by a grating.

Spectrum.—A band of light showing in orderly succession the rainbow colours or isolated bands or colours corresponding to different wavelengths, as seen through a spectroscope or photographed in a spectrograph. The visible spectrum is only a small region in the vast spectrum of electro-magnetic waves, which extend from the longest radio waves to the minutely short waves (gamma rays) emitted by radioactive elements. An *emission* spectrum is produced by the glowing vapour of elements (particularly metals) and consists of bright narrow lines of definite wavelengths. A *continuous spectrum* is the band of all the rainbow colours, red, orange, yellow, green, blue, and violet, merging one into the other, produced by all incandescent solids. An *absorption spectrum* is the series of dark bands crossing a continuous spectrum, seen when white light has been transmitted through a coloured vapour, liquid, or solid.

Step- or **Trap-cut.**—A style of cutting used for coloured stones and sometimes for diamond, in which a series of facets both above and below the girdle have edges parallel to those of the rectangular table facet.

Symmetry.—There are three 'elements of symmetry' recognized in crystallography: planes of symmetry, axes of symmetry, and a centre of symmetry. On this basis crystals can be divided into 32 *classes*. These in turn are grouped into six *systems*. See page 224.

Synthetic stones.—Manufactured stones which have essentially the same composition, crystal structure, and properties as the natural mineral they represent.

Transparency or **Diaphaneity.**—The degree to which light is transmitted through a substance. A stone is termed *transparent* when objects can be clearly seen through it, as through glass; e.g., quartz, diamond, etc. Where some light is transmitted but no clear outlines can be discerned the stone is termed *translucent*; e.g., jade. Where no light can pass through, the substance is *opaque*; e.g. pyrites.

Troy weight.—These are the weights used for precious metals. The equivalents are: 24 grains = 1 pennyweight; 20 pennyweights = 1 ounce; 12 ounces = 1 pound. Note that the Troy grain is the same as the Avoirdupois grain, but that the ounce and pound are larger on the Troy scale. 1 ounce Troy = 31·103 grams: 1 ounce Avoirdupois = 28·35 grams.

Twin crystals.—Two or more crystals of a mineral which have grown together in symmetrical fashion in such a manner that the parts of the twin have some crystallographic direction or plane in common, but others in reversed position.

Ultra-violet light.—Invisible rays of wavelength somewhat shorter than those of visible violet light.

Uniaxial.—Minerals having a unique direction of single refraction—i.e., one optic axis. Tetragonal and hexagonal crystals are uniaxial.

X-rays.—Electro-magnetic radiations having the same nature as visible light but of much shorter wavelength (usually less than 2 Ångströms). Sometimes termed Röntgen rays, after their discoverer.

The following comprehensive table resembles in many respects the admirable summary given in Kraus and Slawson's *Gems and Gem Materials* (see page 311). The alphabetical arrangement enables the reader to refer quickly to the more important properties of the chief gem minerals, and a page reference in the last column suggests where he may turn for fuller details of any particular gem. Chemical formulae have been written in the 'dualistic' form (e.g., $MgO.Al_2O_3$ in place of $MgAl_2O_4$) as this may be more easily comprehended. Omissions and even inconsistencies are for the most part deliberate.

ALPHABETICAL SUMMARY OF GEM SPECIES

Species, Composition and Cryst. System	Varieties and Colours	H.	S.G.	Mean R.I. and D.R.	Notes, and main page reference
AMBER Hydrocarbon Amorphous	*Baltic*—Yellow *Sicilian*—Reddish-yellow *Rumanian*—Brown *Burmese*—Yellow to brown	$2\frac{1}{2}$	1·08	1·54 Isotropic	A fossil resin. Often includes insects, etc. Splinters under knife. Melts at 280° C. Burns with characteristic fumes. Page 265.
ANDALUSITE $Al_2O_3.SiO_2$ Rhombic	Green, greenish-brown, with reddish tints *Chiastolite* is impure variety showing greyish cross on black ground	$7\frac{1}{2}$	3·15	1·64 0·010	Striking pleochroism. Rare. Often confused with tourmaline, but has lower D.R. and higher S.G. Page 219.
APATITE $Ca_4(CaF)(PO_4)_3$ Hexagonal	Yellow, blue	5	3·21	1·638 0·003	Blue type from Burma, strongly dichroic. Yellow commonly shows rare earth absorption bands (5840 Å, etc.). Very low D.R. and higher S.G. distinguish it from danburite.
AXINITE Complex borosilicate of Ca, Al, Mg. Triclinic	Clove brown, violet	7	3·28	1·685 0·011	Occurs in beautiful bladed crystals: hence name. Seldom cut.
BENITOITE $BaO\ TiO_2\ 3SiO_2$ Hexagonal	Sapphire blue	$6\frac{1}{2}$	3·67	1·78 0·047	Rare and beautiful stone from San Benito County, California only. Strong dichroism, strong D.R. and high dispersion.

Species, Composition and Cryst. System	Varieties and Colours	H.	S.G.	Mean R.I. and D.R.	Notes, and main page reference
BERYL $3BeO.Al_2O_3$ $6SiO_2$ Hexagonal	Emerald—Green	$7\frac{1}{2}$	2·71	1·575 0·006	Emerald usually flawed. S. African emerald rather higher S.G. and R.I.; Brazilian emerald rather lower. Page 183.
	Aquamarine—Pale blue to bluish-green	$7\frac{1}{2}$	2·69	1·575 0·006	Aquamarine usually flawless. Madagascar type shows strong dichroism. Page 191.
	Golden beryl (Heliodor)— Yellow	$7\frac{1}{2}$	2·68	1·57 0·005	
	Pink beryl (Morganite)— Rose-pink Also colourless	$7\frac{1}{2}$	2·80	1·59 0·008	Constants of pink beryl usually high because of rare alkalis present. Page 212.
BLENDE (Sphalerite) ZnS Cubic	Brown, yellow, orange, black Transparent to opaque	$3\frac{1}{2}$	4·09	2·37 none	Magnificent colour, lustre, and 'fire'. But too soft to take or retain high polish. Perfect dodecahedral cleavage. Page 219.
BRAZILIAN-ITE $NaAl_3(OH)_4$ $(PO_4)_2$	Greenish-yellow Transparent or translucent	$5\frac{1}{2}$	2·99	1·612 0·021	Discovered in 1944 in pegmatite in Minas Gerais, and (1947) in New Hampshire, U.S.A.
CHRYSO-BERYL $BeO.Al_2O_3$ Rhombic	Alexandrite—Green in daylight, red in artificial light	$8\frac{1}{2}$	3·71	1·75 0·009	Siberian alexandrites show best colour-change. So-called synthetic alexandrites are synthetic corundum or spinel. Page 194.
	Cat's-eye (Cymophane)— Greenish or brownish yellow, translucent and chatoyant Also yellow, greenish yellow, and brown	$8\frac{1}{2}$	3·71	1·75 0·009	Several other species show chatoyancy, but 'Cat's-eye' without qualification signifies chatoyant chrysoberyl. Page 258.
CORUNDUM Al_2O_3 Hexagonal (Trigonal)	Ruby—Red	9	3·99	1·765 0·008	Burma ruby, bright red, strong dichroism. Contains 'silk'. Page 167. Siam ruby, garnet red, less dichroism. No 'silk'.
	Sapphire—Blue Also colourless, yellow, pink, green, and violet	9	3·99	1·765 0·008	Sapphire shows strong dichroism. Page 177. Green sapphire has slightly higher S.G. and R.I. than others. Synthetic corundum made in many colours.
	Star ruby, star sapphire— Translucent, showing asterism				Beware of synthetics. Page 260.

Species, Composition and Cryst. System	Varieties and Colours	H.	S.G.	Mean R.I. and D.R.	Notes, and main page reference
DANBURITE CaO.B$_2$O$_3$. 2SiO$_2$ Rhombic	Pale yellow, colourless	7	3·00	1·633 0·006	Lower S.G. and D.R. distinguish it from topaz. Didymium absorption spectrum frequently present. Burma chief locality.
DIAMOND C Cubic	Colourless Shades of yellow and brown Rarely blue, red, green. (*Boart* and *carbonado* for industrial use only)	10	3·52	2·418 Isotropic	Hardest known substance. Perfect octahedral cleavage Very constant properties. Turned green by radium treatment. Page 152.
DIOPSIDE Monoclinic CaO.MgO. 2SiO$_2$	Pale green to dark green. Sometimes chatoyant	5	3·29	1·69 0·030	Distinguished from peridot by different shade of green and somewhat higher R.I. and lower D.R. From enstatite by higher D.R.
ENSTATITE MgO.SiO$_2$ Rhombic	Green Sometimes chatoyant	5½	3·27	1·67 0·009	Associated with diamond and pyrope in Kimberley district. Also found in larger pieces but of less attractive green in Burma. Absorption line at 5060 Å.
EPIDOTE Silicate of Ca and Al Monoclinic	Dark brownish green	6½	3·45	1·75 0·035	Colour of crystals usually too dark to make attractive gems. Strongly dichroic. Distinctive 'pistachio' green.
EUCLASE Be(AlOH) SiO$_4$ Monoclinic	Pale green or blue	7½	3·10	1·665 0·019	Very ready cleavage (hence name). Appearance and ref. indices almost identical with fibrolite. Distinguished by lower S.G.
FELDSPAR GROUP ORTHOCLASE K$_2$O.Al$_2$O$_3$. 6SiO$_2$ Monoclinic	*Yellow orthoclase*	6	2·56	1·525 0·005	Important group of rock-forming minerals. Only moonstone is used at all widely in jewellery. Page 261. Yellow, orthoclase, found in Madagascar, contains iron. Amazonite, somewhat similar to poor quality turquoise.
	Moonstone—Colourless with white or bluish sheen	6	2·57	1·53 0·008	
MICROCLINE Same composition Triclinic	*Amazonite*—Green, opaque	6	2·56	1·53 0·008	
PLAGIOCLASES Na and Ca alumino-silicates Triclinic	*Oligoclase*—Pale yellow	6	2·64	1·545 0·007	
	Labradorite — Grey with play of colour	6	2·70	1·565 0·010	
	Sunstone—Spangled reddish	6	2·64	1·54 0·009	

Species, Composition and Cryst. System	Varieties and Colours	H.	S.G.	Mean R.I. and D.R.	Notes, and main page reference
FIBROLITE $Al_2O_3.SiO_2$ Rhombic	Pale blue	$7\frac{1}{2}$	3·25	1·665 0·019	Same refractive indices as euclase, and also has very ready cleavage.
FLUORSPAR CaF_2 Cubic	Purple, blue, green, yellow, pink, colourless *Blue John* or *Derbyshire spar*—Massive banded	4	3·18	1·434 Isotropic	Perfect octahedral cleavage. Bright fluorescence under ultra-violet light. Very constant S.G. and R.I.
GARNET GROUP Cubic					Almandine and pyrope form continuous isomorphous series of red garnets. Almandine coloured by iron. Finest pyropes coloured by chromium. Almandine characteristic absorption spectrum.
ALMANDINE $3FeO.Al_2O_3. 3SiO_2$	Purplish red	$7\frac{1}{2}$	3·9– 4·2	1·76– 1·81	
PYROPE $3MgO.Al_2O_3. 3SiO_2$	Deep blood-red	$7\frac{1}{4}$	3·7– 3·9	1·73– 1·76	
GROSSULAR $3CaO.Al_2O_3. 3SiO_2$	*Hessonite*—Orange-brown Also, green massive grossular	$7\frac{1}{4}$ 7	3·65 3·49	1·74 1·73	Hessonite also contains almandine. Resembles jade.
ANDRADITE $3CaO.Fe_2O_3. 3SiO_2$	*Demantoid*—Green *Topazolite*—Yellow	$6\frac{1}{2}$	3·85	1·89	Very high dispersion ('fire') Page 233.
SPESSARTITE $3MnO.Al_2O_3. 3SiO_2$	Orange or yellow	7	4·16	1·80	Rare. Often resembles hessonite. Constants near those for almandine Page 235.
HAEMATITE Fe_2O_3 Hexagonal	Gun-metal black in crystals or when polished	6	5·1	Very high	Brilliant metallic lustre: used in seal stones, and to simulate black pearl. Leaves red streak on unglazed porcelain. Page 285.
IDOCRASE (Vesuvianite) Ca and Fe silicate Tetragonal	Brown, yellow, green; transparent *Californite* — Green massive; semi-opaque	$6\frac{1}{2}$ $5\frac{1}{2}$	3·38 3·3	1·70 0·005 1·70	Distinct dichroism. Californite variety resembles jade. Absorption band in blue at 4610 Å.
IOLITE (Cordierite, Dichroite) Mg, Fe, silicate and Al Rhombic	Blue	7	2·59	1·535 0·009	Very strong pleochroism: dark blue, pale blue, and pale brown being three colours seen.

Species, Composition and Cryst. System	Varieties and Colours	H.	S.G.	Mean R.I. and D.R.	Notes, and main page reference
JADEITE Monoclinic $Na_2O.Al_2O_3.4SiO_2$	Green, white, brown, mauve: translucent	7	3·33	1·66 0·012	'Chinese jade'. Fibrous or granular structure. Often shows slightly dimpled surface. Colour often variegated. More highly esteemed than Nephrite. Page 244.
KORNERU-PINE Mg, Al silicate Rhombic	Green, brownish green, yellow; transparent	6½	3·32	1·675 0·013	Strongly dichroic. Rare; but attractive stones found in Ceylon.
KYANITE $Al_2O_3.SiO_2$ Triclinic	Blue; sometimes green or colourless	4 to 7	3·69	1·72 0·016	Flaky structure. Sometimes fine sapphire blue. Strong pleochroism. Hardness varies greatly with direction.
LAPIS LAZULI Complex silicate, containing sulphur Cubic	Blue; opaque	5½	2·8	1·5	Brassy specks of pyrites frequent. Inferior pieces have white patches. Not a pure mineral, but a rock. Page 355.
LAZULITE Fe, Mg, Al phosphate Monoclinic	Blue; translucent	5½	3·1	1·62 0·031	Rare ornamental stone; sometimes resembles turquoise. Page 255.
MALACHITE $Cu_2(OH)_2CO_3$ Monoclinic	Green, mottled; opaque	4	3·8	1·78 0·025	Ornamental stone with typical concentric bands of dark and paler green. Effervesces with acid.
NEPHRITE Ca, Mg, Fe silicate Monoclinic	Green, white; translucent to opaque	6½	2·96	1·62	Classed with jadeite as true jade. Tough. Splintery fracture. Colour less bright than jadeite. Page 246.
OPAL SiO_2+nH_2O Amorphous	Fire opal—Orange. Seldom shows play of colour	6	2·00	1·45 Isotropic	Contains a varying amount of water. Often porous; thus not advisable to test in heavy liquids. Fire opal usually faceted with domed table. Others cabochon cut. Page 226.
	White opal—Play of colour on plae, translucent background	6	2·1	1·45	
	Black opal—Play of colour on dark background	6	2·1	1·45	
	Water opal—Play of colour within almost colourless stone	6	2·00	1·45	

Species, Composition and Cryst. System	Varieties and Colours	H.	S.G.	Mean R.I. and D.R.	Notes, and main page reference
PEARL CaCO₃ with conchyolin and water	*'Oriental'*—White or creamy *Australian*—Silvery white *Venezuelan*—Translucent white *Black*—Bronze or gun-metal colours *Blue*—Lead grey, due to dark nucleus *Freshwater*—Dull, iridescent *Conch*—Pink; no pearly lustre *Clam*—Black; no pearly lustre	3½ 3½ 3½ 3½ 3½ 3½ 3½ 3½	2·71 2·74 2·7 2·65 2·6 2·7 2·85 2·65	— — — — — — — —	Many localities omitted from summary. 'Oriental' pearls from Persian Gulf and coasts of Ceylon. Pearls also classified by shape—button, drop, baroque (irregular), etc. Pearls consist of about 90 per cent CaCO₃ in form of aragonite. Pink conch pearl and black clam pearl have no pearly lustre and belong to different category. For distinction between pearl and cultured and imitation types, see page 270 *et seq.*
PERIDOT (Olivine) 2(Mg, Fe)O. SiO₂ Rhombic	Green	6½	3·34	1·67 0·036	The mineralogist's olivine. Green type from Red Sea, Arizona, Burma, etc., contains about 8 per cent Fe. 'Doubling' of back facets easily seen. Page 239.
PHENAKITE 2BeO.SiO₂ Hexagonal	Commonly colourless	7½	2·96	1·662 0·016	Peculiarly bright and silvery appearance makes it an attractive gem when well cut.
PREHNITE Ca, Al Silicate Rhombic	Pale green or greenish yellow; translucent	6	2·87	1·63 0·030	Ornamental stone. Sometimes resembles jade. Page 250.
PYRITES FeS₂ Cubic	Brassy yellow metallic lustre Opaque	6	4·9	—	The 'marcasite' of the jewellery trade. In nature, Marcasite is a separate mineral species. Much used in cheap jewellery. 'Fool's gold'. Page 263.
QUARTZ SiO₂ Hexagonal	*Rock-crystal*—Colourless *Amethyst*—Purple *Citrine*—Yellow *Cairngorm*—Brown *Morion*—Smoky brown *Rose quartz*—Pink, cloudy *Aventurine*—Green, spangled	7	2·65	1·548 0·009	Transparent varieties of quartz have very constant properties. Name 'topaz' should not be used for the yellow citrine or brown cairngorm. Jasper is a very impure massive quartz usually brown; stained with Berlin blue to make 'Swiss Lapis'. Page 221.

Species Composition and Cryst. System	Varieties and Colours	H.	S.G.	Mean R.I. and D.R.	Notes, and main page reference
QUARTZ SiO₂—contd. (Trigonal)	*Quartz Cat's-eye*—Pale brown chatoyant *Tiger's-eye or 'crocidolite'* — Golden brown, chatoyant *Rutilated quartz*—Colourless with included rutile	7	2·65	1·548 0·009	
CHALCEDONY GROUP (Crypto-crystalline Quartz)	*Chalcedony*—Unbanded, grey *Cornelian*—Red *Chrysoprase*—Apple green *Agate*—Concentric bands of various colours *Onyx*—Horizontal bands *Sardonyx*—Red and white bands	7	2·6	1·53 Small D.R.	The chalcedony minerals are translucent. They may be stained various colours, and are usually so treated. Many variety names omitted from this table for reasons of space. Page 221.
RHODOCHRO-SITE MnCO₃ Hexagonal (Trigonal)	Rose red; translucent	4	3·6	1·71 0·22	Attractive ornamental stone. Soft; effervesces with acid.
RHODONITE MnO.SiO₂ Triclinic	Rose red; translucent	6	3·6	1·72 0·011	Resembles above. Harder; black markings common. Page 263.
SCAPOLITE Group of complex silicates, etc. Tetragonal	Pale yellow; transparent Pink chatoyant. Violet chatoyant	6 6	2·70 2·63	1·57 0·021 1·545 0·009	Pale yellow, from Brazil. Chatoyant types, from Burma.
SINHALITE Mg(AlFe)BO₄ Rhombic	Pale yellow to dark brown or greenish. Transparent	6½	3·48	1·685 0·038	Cut stones formerly thought to be 'brown peridot' were found (1952) to be a new species. Named after Ceylon, where first found. Distinguished from peridot by S.G., R.I. and spectrum. Page 218.
SMITHSONITE ZnCO₃ Hexagonal (Trigonal)	Yellow or apple green; translucent	5	4·35	1·73 0·23	May resemble chrysoprase or jadeite. Effervesces with acid. 'Bonamite' a trade name.

Species, Composition and Cryst. System	Varieties and Colours	H.	S.G.	Mean R.I. and D.R.	Notes, and main page reference
SPHENE (Titanite) $CaO.TiO_2.SiO_2$ Monoclinic	Yellow, green, brown	5½	3·53	1·96 0·134	Rare. Highly valued in spite of softness for its magnificent appearance. Dispersion higher than diamond. Strong pleochroism and large D.R. Page 199.
SPINEL $MgO.Al_2O_3$ Cubic	Red, pink, pale greyish blue, dark greenish blue, shades of reddish purple *Ceylonite* or *Pleonaste* Black; opaque *Gahnospinel* Shades of blue, containing varying proportions of zinc	8 8 8	3·60 3·8 to 3·98	1·717 Isotropic 1·78 to 1·747	Pure spinel has S.G. 3·58, R.I. 1·715. Variety names such as 'Balas ruby' are misleading and should be avoided. Ceylonite types contain much iron, raising S.G. and R.I. Page 240. Synthetic spinels made in colours to represent other species. Page 240.
SPODUMENE $Li_2O.Al_2O_3.4SiO_2$ Monoclinic	*Kunzite*—Lilac *Hiddenite*—Green Also yellow	7	3·18	1·67 0·015	Easy cleavage in two directions. Pleochroism distinct or strong. Page 212. True green hiddenite coloured by chromium, very rare.
TOPAZ Fluo- or hydroxy-silicate of aluminium Rhombic	Colourless Yellow ⎫ Pink ⎭	8	3·56 3·53	1·62 0·010 1·63 0·008	True topaz not to be confused with yellow quartz. Perfect basal cleavage. Pink stones produced by heat treatment of brownish yellow Brazilian material. Distinct pleochroism. Page 206.
TOURMALINE Complex boro-silicate of Al, Mg, Fe, alkalis, etc. Hexagonal (Trigonal)	*Achroite*—Colourless *Rubellite*—Red, deep pink *Indicolite*—Deep inky blue Also green, pink, yellow, brown, black and parti-coloured	7	3·05	1·63 0·018	Strongly dichroic. Pyro-electric. Colour often in segments or concentric zones. Red types have lowest S.G. Yellow, blue, higher; black highest. Distinguished from topaz and andalusite by stronger D.R. Page 236.
TURQUOISE Hydrous phosphate of aluminium and copper Triclinic	Dark to pale sky blue, pale greenish blue Translucent to opaque	6	2·6 to 2·8	1·61	Egyptian (strong blue, translucent) and Persian (fine blue) are least porous and have S.G. near 2·8. American types softer, more porous and have lower S.G. Veins of dark limonite matrix frequent. Page 253.

Species, Composition and Cryst. System	Varieties and Colours	H.	S.G.	Mean R.I. and D.R.	Notes, and main page reference
ZIRCON $ZrO_2.SiO_2$ Tetragonal	Colourless, blue, yellow, golden brown. Green and shades of green	$7\frac{1}{2}$ $6\frac{1}{2}$	4·69 4·0 to 4·5	1·95 0·059 1·79 up-wards	Heat-treated types from Indo-China and Siam have properties of normal zircon as given. Strong D.R. a distinguishing feature. Green types from Ceylon are semi-amorphous, and have lower and variable properties. Blue zircon the only type to show di-chroism.　　　Page 198.

THE CRYSTAL SYSTEMS

Just as the position of a point on a plane surface can be defined by its perpendicular distance from *two* intersecting lines of reference, or 'axes', so can the position of a plane be defined by the intercepts it makes with *three* intersecting axes. Crystals which have grown under favourable conditions are bounded by flat planes known as *crystal faces*, which are symmetrically disposed. The *crystal axes* chosen as a frame of reference for these faces are imaginary lines passing through the crystal along the directions of greatest symmetry and intersecting in the *'origin'* at the centre of the crystal. All crystals are found to fall into one or other of six main symmetry groups called the *crystal systems*, which are characterized by the nature of their crystal axes. In any mineral, the intercepts made by similar faces with the crystal axes are the same, no matter what the relative dimensions of the faces may be. Further, the angle between two given faces is always the same for all specimens of any one mineral, even if the crystal appears to lack symmetry owing to uneven growth.

The typical crystal form assumed by a mineral is known as its *'crystal habit'*, or simply *'habit'*, and is of great assistance in recognizing the mineral in its rough state. The habit of a mineral may vary somewhat with its locality, but the forms it displays will always belong to the same crystal system. Almost all minerals are crystalline. Non-crystalline materials such as the glasses and resins, which have no regular internal structure and thus no characteristic external form, are known as *amorphous*, meaning 'without shape'.

Minerals are often found to be composed of two or more crystal individuals growing together in a symmetrical manner. Such composite crystals are known as *'twins'*. The word *'macle'* is also used, especially by diamond cutters, for twinned crystals.

Readers wishing to know more about crystallography are recommended to read a good elementary text-book on mineralogy, such as Rutley's *Mineralogy*, published by Thomas Murby, London.

A summary of the six crystal systems is given below, together with the most important gem minerals crystallizing in each system.

1. **Cubic system.**—All forms in this sytem can be referred to three equal axes at right-angles to each other. Cubic minerals are optically isotropic. Common forms are the cube (6 square faces), octahedron (8 triangular faces), and rhombic dode-cahedron (12 rhomb-shaped faces). Diamond, spinel, the garnets, fluorspar, blende and pyrites belong to the cubic system.

2. **Hexagonal system.**—Forms in this system are referred to four axes, three of which are equal and interesct at angle of 60°, the fourth and principal axis being perpendicular to these and of different length. Hexagonal minerals are uniaxial.

Common forms are hexagonal prisms (6 faces), basal pinacoids (2 faces), hexagonal bipyramids (12 faces), and rhombohedrons (6 faces).

Beryl, corundum, tourmaline, quartz, apatite, benitoite, and haematite are in this system.

In the most symmetrical crystals of the hexagonal system (e.g. beryl), the principal axis is one of six-fold symmetry. Most of the gemstones noted above belong to the **trigonal** or **rhombohedral** sub-division of the system, in which this axis possesses only three-fold symmetry.

3. **Tetragonal system.**—Three axes at right-angles, two of which are equal, the third (principal) axis being longer or shorter than these. Tetragonal minerals are uniaxial. Common forms are prisms (4 faces), basal pinacoids (2 faces), bipyramids (8 faces).

Zircon, idocrase, and cassiterite belong to this system.

4. **Rhombic** (orthorhombic) system.—Three axes at right-angles, none of which are equal. Rhombic minerals are biaxial. Common forms are prisms (4 faces), pinacoids (2 faces), and bipyramids (4 faces).

Peridot, chrysoberyl, topaz, andalusite, danburite, and iolite crystallize in this system.

5. **Monoclinic system.**—Three unequal axes, two of which intersect at an oblique angle, the third being perpendicular to these two. Monoclinic numerals are biaxial. Common forms are prisms (4 faces), domes (4 faces), and pinacoids (2 faces).

Jadeite, nephrite, sphene, and spodumene are monoclinic minerals.

6. **Triclinic system.**—Three unequal axes, all obliquely inclined. Biaxial. Common forms are pinacoids, hemiprisms, and hemidomes, two faces each.

Gemstones in this system include kyanite, turquoise, and labradorite feldspar.

A SHORT LIST OF USEFUL BOOKS

There are many books about precious stones now available for the jeweller who wishes for information outside the scope of the present volume. A list of some of the best of these is given below, with brief descriptive notes which may serve as a rough guide for the prospective purchaser.

'Gemstones', by G. F. HERBERT SMITH, 13th edition, 1958. Published by Methuen at 50/-. 540 pages. Twenty-seven plates and many other illustrations. This famous book has now been completely revised by Dr Coles Phillips, and retains its place as the best reference work on gemstones in the English language.

'A Key to Precious Stones', by L. J. SPENCER, 2nd edition, 1946. Published by Blackie at 10/6. 237 pages. Well illustrated. This is a most lively and entertaining little volume, and is different in many ways from the ordinary text-book. It has the merits and demerits of being written from an individual point of view. Jewellers will disagree with Dr Spencer's attitude towards synthetic stones and in one or two other matters, but should profit from some of his strictures.

'Gems and Gem Materials', by E. H. KRAUS and C. B. SLAWSON, 5th edition, 1947. Published by the McGraw Hill Book Co. at 48/6. 332 pages. The best American text-book on precious stones; it is an attractively illustrated and well-produced volume, printed on thinner paper than formerly and without the coloured plates. The book is clearly and tersely written, without going into much detail. A wide range of gem species is covered, and there are notes on the latest types of synthetic stones. A useful feature is a comprehensive table summarizing the properties and occurrences of each gem species, arranged in alphabetical order. The chapters on synthetic stones and cutting processes are particularly good. There is a new chapter on X-ray methods of crystal analysis.

'Practical Gemmology', by ROBERT WEBSTER, 3rd edition 1957. Published by the N.A.G. Press at 17/6. 180 pages. Illustrated. A brief course in gemmology clearly presented and easy to comprehend. Test questions at the end of each

chapter with answers at the end of the book. Descriptions of individual stones are short, but adequate for most purposes. Particularly useful chapters on imitation stones, and on ivory and tortoiseshell, containing information not found in other books.

'The Gemmologists' Compendium', by ROBERT WEBSTER, 1947. Published by the N.A.G. Press at 15/-. A larger edition of the famous little pocket book first issued in 1937. It contains a useful glossary of gem species and gemmological terms, extensive tables of physical constants, data on absorption spectra (illustrated in colour), logarithm and sine tables, and much other useful information.

'Dictionary of Gems and Gemology', by ROBERT M. SHIPLEY and others, 5th edition, 1951. Published by the G.I.A. 261 pages. A new and improved edition of a very full and useful glossary of over 4,000 names and terms. Much technical information is given in abbreviated form under the appropriate headings.

'The Jeweler's Dictionary'. Published by The Jewelers' Circular, Keystone, New York. 2nd edition, 266 pages, 52/-. A very useful reference book covering gemstones, metals, and all terms used in the jewellery trade. Compiled under the guidance of Dr F. H. Pough.

'Handbook of Gem Identification', by RICHARD T. LIDDICOAT, JR. 5th edition, 1957. Published by the Gemological Institute of America. 294 pages. The only other book so far published which attempts to cover similar ground to the present work. There are inevitable similarities, but also great differences in treatment. The book is well illustrated, including many photomicrographs by Dr E. Gübelin.

'Inclusions as a Means of Gemstone Identification', by EDWARD J. GÜBELIN. Published by The Gemological Institute of America, Los Angeles, 1953. 220 pages, 258 illustrations. A valuable introduction to a most interesting and important aspect of gemmology by its leading exponent.

'A Field Guide to Rocks and Minerals', by F. H. POUGH. 2nd edition, 1955. Published by the Riverside Press, Cambridge, Massachusetts. 349 pages, 30/-. The only really practical guide available for those interested in identifying minerals in the field. Extensively illustrated from splendid photographs in colour and black and white. A handy, pocketable volume.

'Popular Gemology', by RICHARD M. PEARL. Published by John Wiley & Sons, New York, and Chapman & Hall, London, 1948. 316 pages. Illustrated. An attractively written book which contrives to be popular without being inaccurate. Contains a good chapter on luminescence.

'Dana's Textbook of Mineralogy'.—Fourth edition, by W. E. FORD. Published by John Wiley & Sons, and Chapman & Hall, 1932 (reprinted 1947), 851 pages. Without doubt the best and most complete general text-book of mineralogy at present available. In addition to a full account of crystallography, optical and physical characters, etc., the book contains an adequate description of every known mineral up to 1932. Any serious student of gemmology will find this book invaluable.

Those interested in gemmology are also advised to subscribe to the following specialist journals, which provide information on all the latest developments in the subject:

'The Journal of Gemmology'. Quarterly, from the Gemmological Association of Great Britain, Saint Dunstan's House, Carey Lane, London, E.C.2.

'The Gemmologist'. Monthly, from the N.A.G. Press Ltd, 226 Latymer Court, Hammersmith, London, W.6.

'Gems and Gemology'. Quarterly, from the Gemological Institute of America, 11940 San Vicente Boulevard, Los Angeles 49, California, U.S.A.

SPECIFIC GRAVITY TABLE

Copal	...	...	1·06	Talc	...	...	2·75	Topaz (white) ... 3·56

Copal ... ... 1·06
Amber ... ... 1·08
Bakelite ... ... 1·26
Tortoiseshell ... 1·30
Erinoid ... ... 1·33
Celluloid... ... 1·38
Vegetable ivory ... 1·40
Ivory ... ... 1·8
Bone ... ... 2·0
Fire opal ... 2·00
Opal ... ... 2·1
Silica glass ... 2·21
Sodalite ... ... 2·3
Hambergite ... 2·35
Petalite ... ... 2·39
Moldavite ... 2·35
Obsidian... ... 2·35
Leucite ... ... 2·47
Variscite... ... 2·55
Amazonite ... 2·56
Orthoclase ... 2·56
Moonstone ... 2·57
Iolite ... ... 2·59
Bowenite... ... 2·6
Chalcedony ... 2·6
Scapolite (pink)... 2·63
Sunstone... ... 2·64
Quartz ... ... 2·65
Synth. emerald ... 2·65
Coral ... ... 2·68
Aquamarine ... 2·69
Beryl (yellow) ... 2·69
Pseudophite ... 2·7
Emerald ... ... 2·71
Labradorite ... 2·70
Scapolite (yellow) 2·70
Calcite ... ... 2·71
Pearl (oriental) ... 2·71
Pearl (cultured) 2·75

Talc ... ... 2·75
Turquoise ... 2·8
Lapis lazuli ... 2·8
Beryllonite ... 2·82
Conch pearl ... 2·85
Prehnite ... ... 2·87
Verdite ... ... 2·9
Pollucite ... ... 2·92
Aragonite ... 2·94
Datolite ... ... 2·95
Phenakite ... 2·96
Nephrite... ... 2·96
Brazilianite ... 2·99
Danburite ... 3·00
Amblygonite ... 3·03
Tourmaline ... 3·06
Lazulite ... ... 3·09
Euclase ... ... 3·10
Zoisite ... ... 3·12
Andalusite ... 3·15
Fluorspar ... 3·18
Spodumene ... 3·18
Apatite ... ... 3·21
Fibrolite ... ... 3·25
Enstatite... ... 3·27
Axinite ... ... 3·28
Diopside ... ... 3·29
Dioptase ... ... 3·30
Kornerupine ... 3·32
Jadeite ... ... 3·33
Peridot ... ... 3·34
Idocrase ... ... 3·38
Rhodizite ... 3·40
Epidote ... ... 3·45
Sinhalite ... ... 3·48
Grossular (massive) 3·5
Diamond... ... 3·52
Sphene ... ... 3·53
Topaz (yellow) ... 3·53

Topaz (white) ... 3·56
Periclase (synth.) 3·59
Rhodonite ... 3·6
Rhodochrosite ... 3·6
Spinel ... ... 3·60
Spinel (synthetic) 3·63
Hessonite ... 3·65
Benitoite... ... 3·67
Staurolite ... 3·70
Pyrope ... ... 3·7
Chrysoberyl ... 3·71
Malachite ... 3·8
Pleonaste... ... 3·8
Demantoid ... 3·85
Anatase ... ... 3·88
Gahnospinel to 3·97
Corundum ... 3·99
Willemite ... 4·03
Blende ... ... 4·09
Zircon (green) 4 to 4·5
Almandine ... 4·2
Spessartite ... 4·16
Rutile (synthetic) 4·25
Smithsonite ... 4·35
Barytes ... ... 4·5
Zircon (blue, white) 4·69
Pyrites ... ... 4·9
Haematite ... 5·05
Strontium titanate 5·13
Cassiterite ... 6·9
Silver ... ... 10·5
Palladium ... 11·3
Gold, 9 carat ... 11·4
Gold, 14 carat ... 13·93
Gold, 18 carat ... 15·4
Gold, 22 carat ... 17·7
Gold, pure ... 19·3
Platinum... ... 21·5

Note.—Where there is a wider variation in the above values than one or two units in the second decimal place, only one place of decimals is quoted.

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REFRACTIVE INDEX TABLE

Stone		R.I.	D.R.
Fluorspar	...	1·434	none
Opal ...	...	1·45	none
Silica glass	...	1·46	none
Sodalite	...	1·48	none
Obsidian	...	1·49	none
Moldavite	...	1·49	none
Leucite	...	1·508 1·509	0·001
Petalite	...	1·504 1·516	0·012
Orthoclase	...	1·522 1·527	0·005
(yellow)			
Iolite ...	...	1·537 1·547	0·010
Scapolite (pink)		1·540 1·549	0·009
Oligoclase	...	1·542 1·549	0·007
Quartz	...	1·544 1·553	0·009
Scapolite	...	1·548 1·568	0·020
(yellow)			
Labradorite	...	1·560 1·570	0·010
Bytownite	...	1·564 1·574	0·010
Hambergite	...	1·555 1·629	0·074
Emerald (synth.)		1·560 1·563	0·003
Aquamarine	...	1·570 1·575	0·006
Emerald	...	1·579 1·589	0·006
Morganite	...	1·58 1·59	0·008
Anorthite	...	1·574 1·589	0·015
Brazilianite	...	1·604 1·624	0·020
Tremolite	...	1·601 1·642	0·040
(green)			
Amblygonite	...	1·612 1·638	0·026
Topaz (white)		1·61 1·62	0·010
Topaz (yellow)		1·630 1·638	0·008
Tourmaline	...	1·62 1·64	0·018
Danburite	...	1·630 1·636	0·006
Apatite	...	1·634 1·637	0·003
Andalusite	...	1·634 1·644	0·010
Barytes	...	1·636 1·648	0·012
Pargasite	...	1·628 1·651	0·023
Datolite	...	1·625 1·670	0·045
Euclase	...	1·652 1·672	0·020
Jadeite	...	1·654 1·667	0·014
Phenakite	...	1·656 1·671	0·015

Stone		R.I.	D.R.
Enstatite	...	1·663 1·673	0·010
Bronzite	...	1·670 1·684	0·014
Fibrolite	...	1·658 1·678	0·020
Axinite	...	1·675 1·685	0·010
Kornerupine	...	1·668 1·680	0·012
Spodumene	...	1·663 1·678	0·015
Diopside	...	1·672 1·702	0·030
Sinhalite	...	1·670 1·708	0·038
Willemite	...	1·691 1·719	0·018
Idocrase	...	1·705 1·710	0·005
(yellow)			
Kyanite	...	1·715 1·732	0·016
Spinel ...	...	1·715	none
Spinel (synth.)		1·727	none
Gahnospinel	...	to 1·75	none
Rhodonite	...	1·733 1·747	0·013
Periclase (synth.)		1·738	none
Rhodochrosite		1·597 1·817	0·220
Epidote	...	1·736 1·770	0·034
Chrysoberyl	...	1·745 1·753	0·009
(yellow)			
Alexandrite	...	1·746 1·755	0·009
Pyrope	...	1·73 to 1·76	none
Sapphire (white)		1·760 1·768	0·008
Ruby ...	...	1·764 1·772	0·008
Benitoite	...	1·755 1·802	0·047
Pleonaste	...	1·78	none
(black)			
Spessartite	...	1·78 to 1·80	none
Almandine	...	1·76 to 1·81	none
Zircon (metamict)		1·79	none
Demantoid	...	1·888	none
Zircon (normal)		1·925 1·984	0·059
Sphene	...	1·900 2·002	0·120
Cassiterite	...	2·002 2·100	0·096
Blende	...	2·37	none
Strontium			
Titanate	...	2·41	none
Diamond	...	2·418	none
Anatase	...	2·493 2·554	0·061
Rutile (synth.)		2·610 2·897	0·287

NAMES AND ADDRESSES OF
RECOMMENDED SUPPLIERS

The following names and addresses may be useful to those who wish to purchase instruments or specimens. This list makes no pretence to be complete.

GREAT BRITAIN

BAIRD & TATLOCK (LONDON) LTD, St Cross Street, London, E.C.1.
   Makers and suppliers of chemical apparatus, glass cells, chemicals, immersion and heavy liquids, etc.

R. & J. BECK, LTD., 69 Mortimer Street, London, W.1.
   Makers of monocular, binocular, and petrological microscopes, lenses, spectroscopes, table spectrometers.

BRITISH DRUG HOUSES, LTD, Poole, Dorset.
   Makers and suppliers of chemicals, immersion and heavy liquids.

GREGORY, BOTTLEY & Co., 30 Old Church Street, London, S.W.3.
   Suppliers of crystals and other mineral specimens.

KENNETH PARKINSON, F.G.A., 11 Fitzroy Street, Hull.
   Supplier of specimens for students and collectors.

RAYNER, 100 New Bond Street, London, W.1.
   Makers of 'Rayner' refractometers, microscopes, spectroscopes, dichroscopes, specific gravity indicators. Suppliers of 1·81 refractometer contact fluid, crystals and cut stones for students' use.

J. H. STEWARD, LTD, 406 Strand, London, W.C.2.
   Makers of 'Herbert Smith' refractometers, dichroscopes, etc.

W. WATSON & SONS, LTD, 313 High Holborn, London, W.C.1.
   Makers of microscopes and other optical apparatus.

For correspondence courses in gemmology and retail jewellery, supply of Chelsea colour filters, special apparatus, text-books, and general advice, apply to the GEMMOLOGICAL ASSOCIATION OF GREAT BRITAIN, Saint Dunstan's House, Carey Lane, London, E.C.2.

UNITED STATES OF AMERICA

BAUSCH & LOMB OPTICAL CO., Rochester, New York.
   Makers of microscopes of all types, lenses, spectroscopes, etc.

SPENCER LENS Co. (American Optical Co.), Buffalo 11, New York.
   Makers of microscopes, lenses and other optical apparatus.

WARD'S NATURAL SCIENCE ESTABLISHMENT, INC., 302 Goodman Street North, Rochester 9, New York.
   Suppliers of crystals and all types of mineral specimens.

For correspondence courses in gemmology, text-books, special apparatus and general advice, apply to the GEMOLOGICAL INSTITUTE OF AMERICA, 11940 San Vicente Boulevard, Los Angeles 49, California.

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Note: The index is a full one, but only *useful* references are given. Heavy type denotes the most important references where this is deemed helpful.

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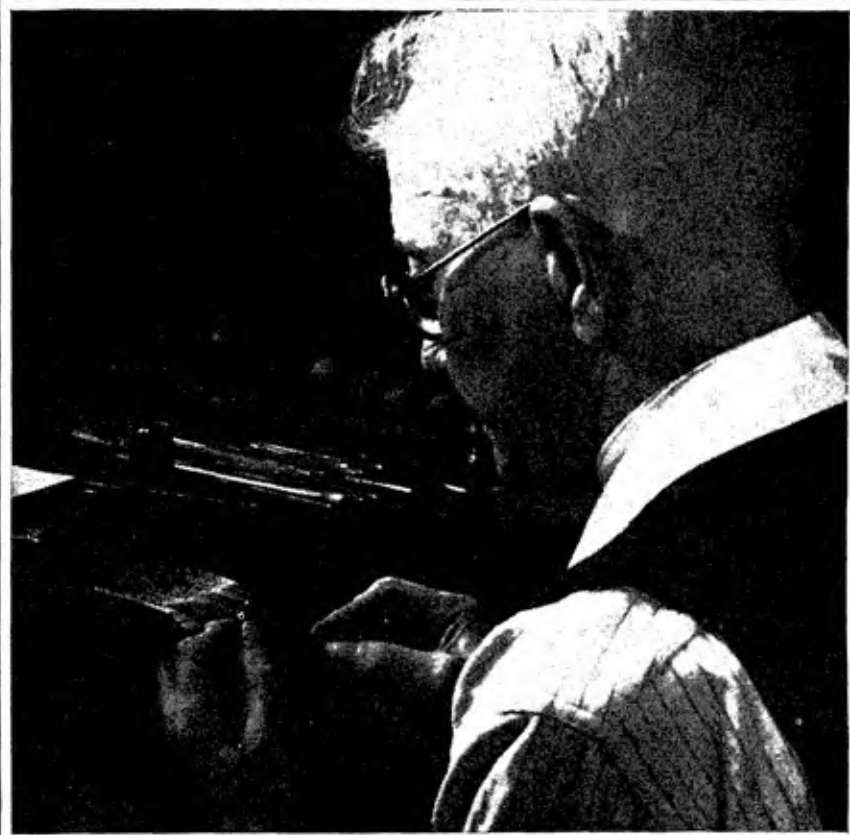
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